

Energy sector study

Phase-1

Submitted to

SWISS DEVELOPMENT COOPERATION
New Delhi

Prepared by

TATA ENERGY RESEARCH INSTITUTE
New Delhi

November 1995

Team members

Somnath Bhattacharjee

J Misra

P R Sobhanbabu

N Vasudevan

Alok Goyal

Kulbushan Kumar

G Gopalakrishnan

TERI deeply consoles the sad demise of Mr J. Mishra, one of the team members, who died in a tragic road accident during the course of the study.

Acknowledgement

TERI places on record the excellent support and valuable guidance provided by Mr Pierre Jaboyedoff, Energy Advisor to SDC, from time to time during the entire course of the study.

TERI acknowledges the critical review of the study reports undertaken by M/s Cast Metals Development, U.K. and M/s British Glass Technology, U.K. for the foundry and glass sectors respectively. TERI acknowledges the visits of Mr John Smith, Cast Metals Development and Mr W.A. Hartley, British Glass Technology for attending the Screening Workshop and providing valuable suggestions.

Last, but not the least, TERI gratefully acknowledges the excellent overall study coordination and valuable guidelines provided by Dr Veena Joshi, SDC. Her valuable guidance helped shaping the study in most practical and meaningful study.

Contents

Executive Summary i - ix

Volume 1

Assessment of the energy use pattern in small scale industry 1 - 10

Volume 2

Energy audit in Agra foundry cluster 1 - 30

Volume 3

Energy audit in Firozabad glass industry cluster 1 - 71

Executive summary

The small scale industry occupies a position of prominence in Indian economy and has become a major force in furthering the process of rapid industrialisation in India. The small scale sector contributes more than 50% to the industrial production in value addition terms, one third of the total export and employs the largest manpower next to agriculture. There are some energy intensive subsectors under the small scale sector, where the cost of energy forms a sizeable proportion of the total production cost and offers tremendous scope for energy conservation vis-a-vis reduction in energy cost through technology upgradation. Many units under the small scale sector are, however, manned by persons without a technical background and are not aware of the technological developments that have taken place over the years. In spite of the fact that the energy cost forms a large share of the product cost, small scale industries find it difficult to undertake/implement energy conservation projects because of lack of technical knowhow.

With the above background, a study was undertaken by TERI on behalf of Swiss Development Cooperation (SDC), which was aimed at helping the small scale industry to improve their energy efficiency. The study report is prepared in three volumes covering the following broad topics.

Vol 1: Assessment of energy use pattern in small scale industries

Vol 2: Energy audit in Agra foundry cluster

Vol 3: Energy audit in Firozabad glass industry cluster

The summary of major findings for each of the above areas are presented in the following sections.

Vol 1: Assessment of the energy use pattern in small scale industries

This component was undertaken to analyse the energy use pattern on a macro level with a view to identify industry clusters, which are energy intensive and presents significant scope for energy consumption. In order to identify such industry clusters, a list of 41 sub-sectors under the 4 digit NIC (National Informatics Centre) code were shortlisted. A district-wise break-up of the number of units under each of these 41 subsectors were obtained from the NIC wing of Development Commissioner, Small Scale Industry. The importance of any

industry sub-sector from the energy view point is a function of its energy intensity as well as the total number of units under that particular subsector. An analysis of the data shows that casting and forging units rank first in this regard, followed by edible oils & fats and glass tiles. These three subsectors account for more than 70% of the total energy use with the 41 subsectors chosen for the study. A pie-chart showing the relative share of energy consumption between different important industry subsectors is shown in **figure 1**.

It was concluded that small scale industry presents an ideal case where substantial scope for improving the energy efficiency exists through better operational practices and technology upgradation. The general level of awareness in the small scale sector with regard to energy conservation is low and the systems/equipments employed are of outmoded design. The entrepreneurs who are interested in improving the system efficiency are constrained by lack of technical knowhow and are also not able to hire the services of consultants. It was felt that successful demonstration of energy saving techniques in one/two units in a cluster will instill the necessary confidence for the entrepreneurs and possibly motivate others to take up similar projects. Once the industry owners are convinced of the benefits of energy conservation by these actual implementation projects, the process of change felt, will become self-sustaining.

Vol 2: Energy audit of the Agra foundry cluster

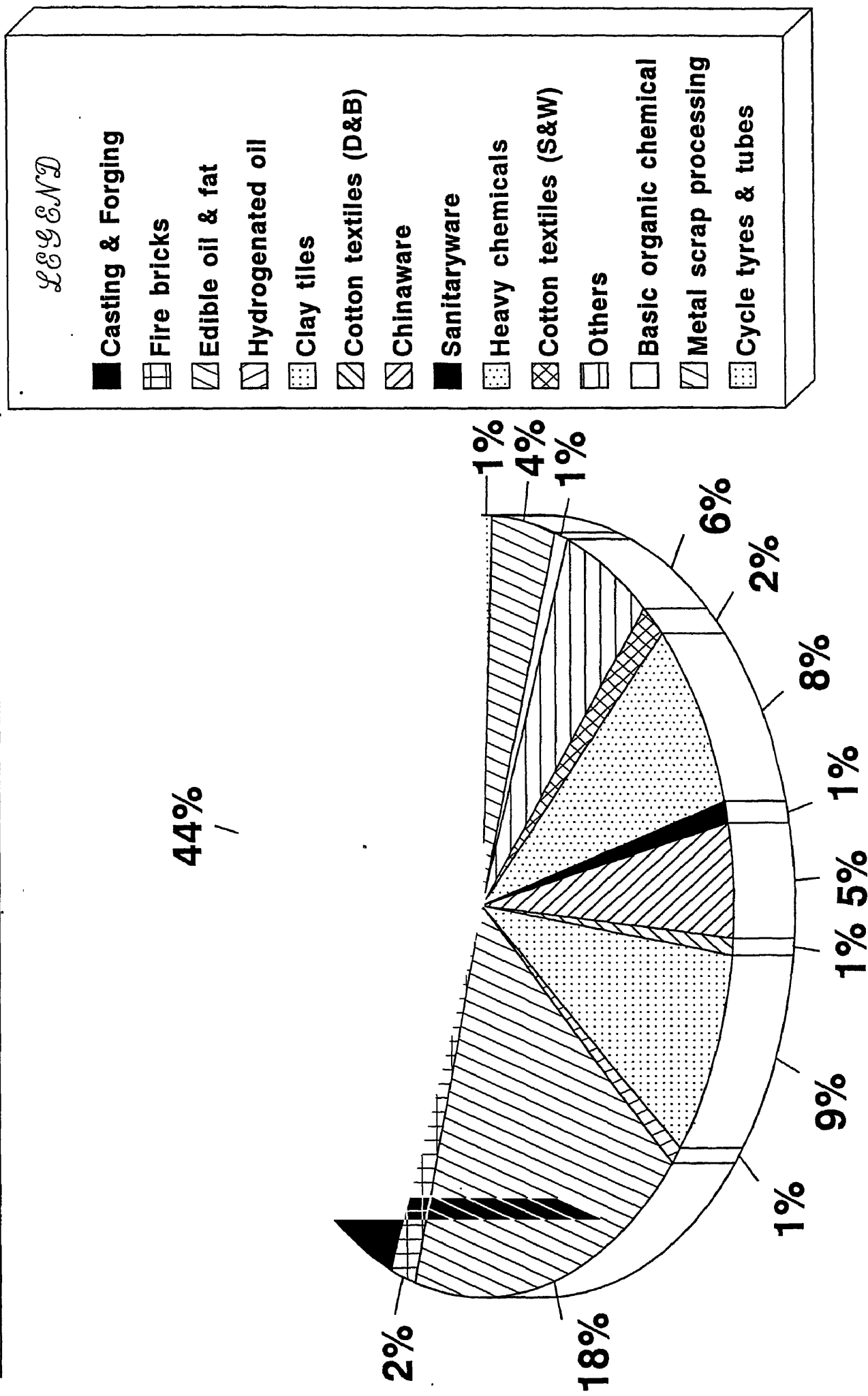
The foundry cluster at Agra consists of 200 cupola based foundry units. The furnaces are of conventional type with only a small percentage of them employing the energy efficient divided blast operation. Most of the units operate twice a week with a melting campaign of 6-8 hours duration. Coke is the primary source of energy used in cupola. In order to identify the scope for energy conservation in the melting furnaces, energy audit was carried out in two representative foundry units; one employing a conventional cupola and the other with a divided blast cupola (DBC). The key results of the energy audit study undertaken in the Agra foundry cluster are shown in **table 1**.

Table 1. Results of the energy audit study at Agra

Furnace type	Coke feed rate	Melting efficiency (%)	Tapping temperature
Conventional blast cupola	1:3.1	18.0	
Divided blast cupola	1:5.3	30.3	

Fig 1: Energy share of 41 energy intensive subsectors

iii



The energy audit study reveals that there is substantial scope for improving the energy efficiency of the furnaces by employing certain energy conservation measures which range from improving the operating practices of the existing cupolas to design modifications. The following conclusions are drawn from the study carried out in the Agra cluster.

- (i) Owners were generally "remote" from the production process with no significant technical/ scientific appreciation of the processes used. In most cases, day to day plant operation is controlled by "experienced operators", (known as "Mistrys") who have traditionally handed down the craft from father to son. Many of these mistrys work for more than one owner. They are considered as expert and not to be questioned on the cupola operation. Most of the mistrys are illiterate, have no scientific or technical training and therefore are not able to assess the efficiency of the furnace operation. It is significant that the most effective foundries visited had abandoned the employment of mistrys. The apathy on the part of majority of foundry owners to upgrade the technology level is clearly reflected from the fact that out of the 200 registered foundry units in the cluster, only 15 units are employing DBC.
- (ii) The cupola furnaces suffer from gross inefficiency. The energy audit study shows that the coke feed rate for the conventional cupola and DBC were only 1:3.1 and 1:5.3 respectively. Both these figures are high for their respective categories.
- (iii) The quality of coke supplied to the foundries is poor and even so ash content and grading is very variable. Ash content is very high and over 30% (good European coke will have an ash content not higher than 10%). Size of the coke is also very variable and it contains both excessive small sized material (75 mm to dust) and large lumps (over 200 mm). The strength of the coke is also very low leading to serious degradation both in storage and in the cupola.

Bad quality coke will depress both the melting rate of the cupola and the attainable metal temperature for a given coke charge and blast rate. Because of the high ash content, the available carbon in the coke will be accordingly low, some of the claims of low coke consumption made by some of the foundries should therefore be treated with circumspection.

- (iv) Many of the cupolas are wrongly sized. Optimum performance of the cupolas requires the correct combination of melting zone area, blast volume and blast pressure. The dimensions relating to cupola well depth, tuyere area and shaft height are also significant. These factors apply whether the furnace is of conventional or divided blast design. It is suspected that many of the cupolas seen had too low a blast rate and pressure. Inefficiencies were made worse by the poor design & conditions of blower, blast main, windbelt and tuyere units and also the deteriorated condition of much of this equipment. There is a substantial scope for improving the efficiency of cupola by proper matching of blast rate, tuyere dimension, shaft height and melt zone diameter.
 - (v) For a properly designed DBC, coke ratio of 1:8 or even less is achievable. This figure is substantially lower than the coke ratio of 1:5.3 found for the DBC studied.
 - (vi) The foundry returns were found to be in the range of 20-40% depending on the type of items cast. This figure is considered high keeping in mind that no stringent quality control procedures are followed by the units. The reduction of foundry return can significantly contribute to energy efficiency, which can be primarily achieved by adopting better mould making practices.
- It was unusual to find any formal system for recording production data, e.g. metal & coke charged, castings produced, reject numbers and causes etc. In general, castings were only rejected due to obvious visible defects and little notice was taken of metallurgical or dimensional quality. Quantitative chemical analysis and metallurgical examination of specimens were only observed in one foundry.
- (vii) The charging is carried out manually and different raw materials are not weighed before being fed into the furnace. The operation of the cupola depends entirely on the experience and judgement of the operator. All these factors indirectly lead to higher coke consumption in the furnaces.
 - (viii) Instrumentation is totally absent and even important parameters like melt temperature are not monitored. Only two foundries in the Agra cluster were found to be aware of the need for, and using, shop floor techniques for the control of metal quality. Proper temperature measurements, thermal analysis for the determination of carbon/silicon contents and wedge tests for the assessment of chilling tendency are important controls if engineer quality castings are to be

produced. Even a simply constructed manometer to indicate variations in blast pressure will enable cupola operating conditions to be monitored and action to be improve melting performance. It should be noted that none of the DBCs in the cluster were fitted with automatic blast control system which would improve the performance further.

- (ix) For the conventional cupolas (which constitutes around 90% of the furnace population in the cluster), the best option identified is to retrofit these furnaces to divided blast operation. The cost of retrofitting, which is expected to be around Rs 50000, will be paid back in less than 2 months.
- (x) The hot blast cupola operating in the cluster had the lowest reported coke consumption. It may be worthwhile considering heat recovery methods using simple recuperative equipment i.e. without combustion of the flue gases.
- (xi) Some other technology options like oxygen enrichment would help in improving the energy efficiency. However, such measures are capital intensive and since the units in Agra are not engaged in long daily melting campaigns, the applicability of these technology options need a more in-depth analysis.

Volume 3: Energy audit in Firozabad glass industry cluster

Firozabad, a small town situated in the state of Uttar Pradesh, has a cluster of small scale glass industries which accounts for nearly 70% of the total glass production in the small scale sector in India. A wide variety of glass products are manufactured in the cluster. Coal is the major source of fuel in the cluster although residual fuel oil (R.F.O) is also used as fuel in some of the units.

The various types of furnaces used for glass melting in the cluster are (1) coal fired regenerative tank furnace, (2) oil fired regenerative tank furnace, (3) open pot furnace and (4) closed pot furnace. In regenerative tank furnaces, part of the sensible heat in flue gases is recovered for preheating the combustion air. However, the pot furnaces do not have any heat recovery systems. Annealing lehrs are used in the cluster for the heat treatment of the finished products. Apart from the melting furnaces and annealing lehrs, muffle furnaces (pakai bhatties) are also employed in the cluster primarily for baking of bangles. An assessment made in the cluster indicates that pot furnaces (both open &

closed types) account for 48% of the total coal consumption followed by muffle furnaces which account for 27%. The remaining 25% coal is consumed in tank furnaces.

Energy audit was carried out in representative units for each of the above furnace types with a view to identify implementable energy saving options for the cluster. The main outcome of the energy audit study is presented below. The specific energy consumption, fuel to melt ratio and the thermal efficiency of different types of furnaces in the Firozabad cluster are shown in **table 2**.

Table 2. Performance of furnaces in Firozabad cluster

Furnace type	Specific energy consumption (Gcal/t of melt)	Fuel-to-melt ratio (kg/kg)	Thermal efficiency (%)
Tank furnace (coal fired)	3.6	0.6	12.7
Tank furnace (oil fired)	2.1	0.2	21.3
Open pot furnace	5.5	1.0	9.8
Closed pot furnace	9.5	1.7	4.7
Muffle furnace	—	—	3.1

Based on the energy audits carried out in representative units in the cluster, the following energy conservation measures were identified for improving the efficiency of energy use in the cluster.

(i) Excess air optimisation

For none of the units, the excess air was maintained at optimum level, leading to low operating efficiency. There is no provision to check the excess air level in any of the units. The excess air level can be optimised by monitoring the O_2/CO_2 level in the flue gases and regulating the combustion air flow accordingly. The investment required will be paid back within a couple of months due to the resulting fuel savings.

(ii) Waste heat recovery

A substantial quantity of heat input is carried away by the flue gases from all types of furnaces. Flue gas loss accounts for almost 50% of the total heat input in pot furnaces and there is a large scope for utilising this waste heat for preheating the combustion air. Even in regenerative tank furnaces, there is a possibility of utilising the sensible heat in the flue gases after the regenerator by using a secondary regenerator. This, however, will require major modification in the tank furnace design.

(iii) Reduction of structural losses

As low quality refractory bricks are used, the structural losses were found to be high in all cases. By upgrading the existing insulation with better refractory material/insulation material, the structural losses can be reduced significantly.

(iv) Reduction of unburnt carbon losses in coal fired furnaces

The high unburnt carbon in bottom ash in coal fired furnaces accounts for about one-third of the heat input. This loss is attributable to improper air-fuel mixing resulting in inefficient combustion and poor ash handling technique adopted by the units. The furnace design need to be modified so as to improve the air-fuel mixing considerably for improving the combustion efficiency.

(v) Internal belt return in annealing lehrs

The heat balance of annealing lehrs shows that about 47% of heat input is taken away by the conveyer system. This loss can be minimised by having internal belt return which would reduce the fuel input by at least one-third.

(vi) Improving the muffle furnace (pakai bhatti) design

The efficiency of the muffle furnace was found to be as low as 3.1%. This is attributed to (a) high flue gas loss, (b) high structural loss and (c) high unburnt carbon loss in the bottom ash. It is concluded that the pakai bhatties need a complete new design to overcome the problem of lower efficiency.

(vii) Use of proper instrumentation

Basic instrumentation such as flue gas analyser, temperature indicators for the glass melt & flue gas and glass level indicator are not employed in the cluster. Proper instrumentation would help in monitoring the operating parameters in the unit with a consequent check on the proper furnace operation.

Apart from the suggestions mentioned above, options such as (a) cullet preheating, (b) oxygen enrichment and (c) use of bubble injector pipes will help in improving the

energy efficiency of the unit. The applicability of these instruments in relatively smaller units encountered in the Firozabad cluster, however, needs a detailed investigation.

In addition to the measures listed above, which were primarily based on unit specific energy audits, some strategies to improve the energy use pattern by the sector as a whole are discussed below.

The flue gases from the pot furnaces are at very high temperatures. This waste heat can be utilised for providing the energy needs of the pakai bhatties. For the closed pot furnaces, the flue gas temperatures were found to be as high as 800-900°C, which can be used for baking of bangles in pakai bhatties, where the maximum temperature encountered is only of the order of 450-500°C.

The design of the producer gas plant in the coal fired tank furnaces is outmoded with very low conversion efficiency. Poor coal and ash handling coupled with total absence of control system also leads to high unburnt carbon in the bottom ash. A common coal gasification system with improved design can cater to 4-5 tank furnace units and can be considered as a long-term option.

Energy pooling

Some preliminary investigations were also carried out with regard to possibility of energy pooling among the different industries with an industrial estate/cluster. Energy pooling primarily means utilising the waste heat/excess energy capacity of one industrial unit to meet the demand of a neighbouring industrial unit leading to an overall improved energy consumption pattern by the cluster. The concept was attempted in the Mayapuri and the Wazirpur industrial clusters in Delhi without much success. The only possibility of energy pooling was identified in the Firozabad glass industry cluster. As already explained, there is a possibility to utilise the waste heat in the pot furnace flue gases for baking of bangles or supplementing the energy requirement for bangle baking in pakai bhatties.

Volume 1

**Assessment of the energy use pattern
in
small scale industries**

CONTENTS

1.0	Introduction	1
2.0	Identification of important industry clusters	2 - 7
3.0	Field visits to some selected industry clusters	8
3.1	<i>Foundry cluster at Howrah (West Bengal)</i>	8
3.2	<i>Pottery industry - Khurja (U.P)</i>	8 - 9
3.3	<i>Lock industry - Aligarh</i>	9
4.0	Conclusion	10

1.0 Introduction

The small scale sector occupies a position of prominence in the Indian economy and has become a major force in furthering the process of rapid industrialisation in India. The small scale sector contributes more than 50% to industrial production in value addition terms, one third of the total export and employs the largest manpower next to agriculture. A study of the growth rate of SSI in the last decade shows that the number of units increased from 5.23 lakhs in 1981-82 to more than 16 lakhs by 1987-88. The value of total production had gone up from Rs.326000 million to Rs.850000 million during the same period. At the same time, the number of sick units has gone up from 25,342 to 1,58,226 and outstanding bank credit against the sick small scale industry units had increased from Rs.3950 million to Rs.15420 million during the period from 1981-88. Thus two contrasting trends - rapid growth and growing sickness has become prominent over the last decade.

In India, a stage has reached, where the small industries have to take off in the area of applied innovations in creating new products and processes for its survival. The escalating cost of energy is also a cause for major concern. There are some energy intensive subsectors where the cost of energy forms a sizeable proportion of the total production cost and offers tremendous scope for energy efficiency vis-a-vis reduction in energy cost through technology upgradation. For the present study, two industry clusters are covered for detailed analysis with regard to energy efficiency. These are the foundry units at Agra and the glass melting furnaces at Firozabad.

An exercise was also carried out to analyse the energy consumption pattern in the small scale sector on a macro level with a view to identify additional clusters, which are energy intensive and presents significant scope for energy conservation. The result of the macro level analysis is presented in the following sections.

2.0 Identification of important industry clusters

In order to identify industry clusters which are important from an energy point of view, a list of 41 energy intensive industry sub-sectors under the 4 digit NIC (National Informatics Centre) code were shortlisted. To arrive at a national picture, a district-wise break-up of the number of units under each of these 41 sub-sectors were obtained from the NIC wing of Development Commissioner, Small Scale Industry. The data is based on the second census of S.S.I. carried out by NIC through its different regional offices in 1988. The glass industry is, however, not included in the present analysis as the glass cluster at Firozabad which was covered in details under the present study, accounts for more than 70% of the total glass manufactured in the small scale sector.

Table 1 gives a consolidated list of the total number of units under each of the 41 selected subsectors on an all India basis as also their energy consumption and value of production. The importance of any industry subsector from an energy view point is a function of both its energy intensity and the total number of units within that particular subsector. Based on the NIC data, the **casting and forging units** were ranked first in this regard followed by **manufacturers of edible oils and fats** and **manufacturer of glass tiles**. These three subsectors combined, accounts for more than 70% of the total energy use within the 41 subsectors chosen for the present analysis.

The location of some important clusters within these three subsectors are presented in **figures 1** through **3**. A pie-chart showing the share of energy use by different subsectors is given in **figure 4**.



Fig. 1 . Location of some important clusters under casting and forging subsector



Fig. 2 Location of some important clusters under edible oil and fat subsector



Fig. 3 Location of some important clusters under clay tiles subsector

LEGEND

-  Casting & Forging
-  Fire bricks
-  Edible oil & fat
-  Hydrogenated oil
-  Clay tiles
-  Cotton textiles (D&B)
-  Chinaware
-  Sanitaryware
-  Heavy chemicals
-  Cotton textiles (S&W)
-  Others
-  Basic organic chemical
-  Metal scrap processing
-  Cycle tyres & tubes

44%

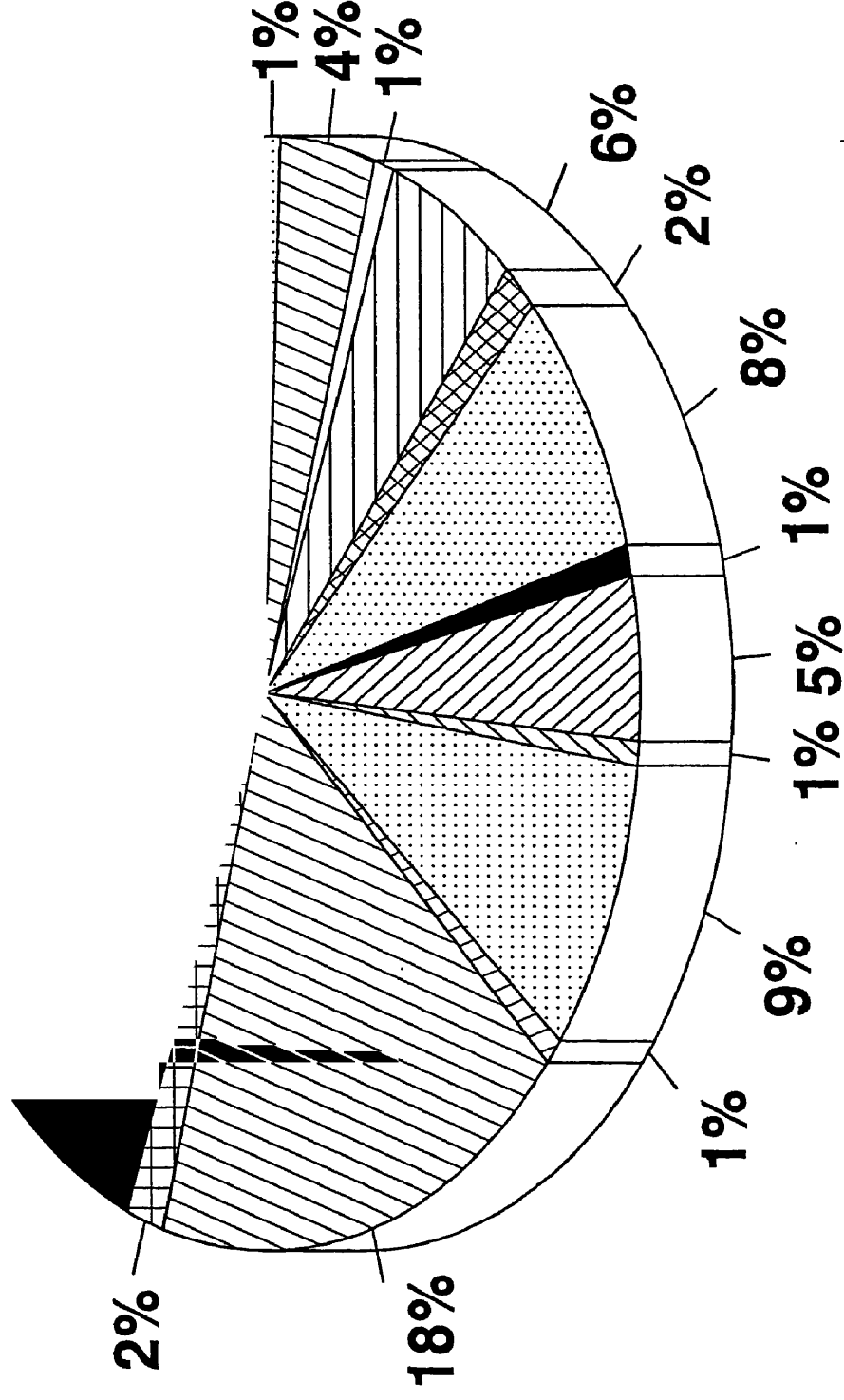


Table 1. Consolidated list of small scale industries

4 digit NIC Code	Name of industry subsector	Total no. of units	Total energy consumption (000'Rs)	Total production (000'Rs)
2021	Artificially dehydrated fruits	55	2618	49820
2023	Manufacture of fruit juice concentrate	217	5576	210601
2026	Canned fruit and vegetables	41	980	66029
2100	Manufacture of hydrogenated oil	166	13954	453554
2110	Manufacture of other edible oils and fat	16400	313443	20015998
2200	Industrial alcohol and blended spirit	39	7950	289318
2311	Spinning and weaving of cotton textiles	641	26250	1552097
2320	Dyeing and bleaching of cotton textiles	64	12366	192982
2420	Spinning, weaving and finishing of wool & silk	138	119	12116
2520	Dyeing/printing and bleaching of jute textiles	2	72	4914
2674	Manufacture of artificial leather	2	159	3324
2749	Manufacture of industrial goods	143	1208	67109
2801	Manufacture of pulp (machine made)	5	559	6120
2802	Manufacture of paper (machine made)	283	9132	214059
2903	Manufacture of industrial leather	207	6357	546195
2909	Manufacture of other leathers	35	549	17736
3002	Manufacture of tyre and tube for cycles	54	13208	294400
3101	Manufacture of heavy inorganic chemical	940	138768	3659312
3106	Manufacture of basic organic chemicals	133	14358	438791
3141	Manufacture of Toilet Soap	111	1853	197335
3169	Manufacture of fibre glass material	76	1061	61490
3181	Manufacture of explosives	20	447	39566
3201	Manufacture of fire bricks	122	27953	123681
3204	Manufacture of clay tiles	1015	149739	718980
3220	Manufacture of earthenware	306	3379	64385
3231	Manufacture of chinaware	550	83069	260858
3232	Manufacture of sanitaryware	111	16253	81553
3233	Manufacture of insulators	84	6195	47260
3311	Manufacture of castings and forged iron	5547	768421	12647128
3316	Manufacture of Tools	111	2169	118439
3317	Manufacture of misc. foundry and forged products	289	8965	325258
3341	Manufacture of brass and rollings	90	2377	178784
3380	Processing of metal scraps	356	71093	2308250
3391	Melting and refining of other metal	120	3094	308418
3433	Manufacture of locks	565	4724	268528
3451	Manufacture of cutlery	273	1618	62731
3718	Manufacture of parts and accessories of locomotives	92	1688	99213
3728	Manufacture of parts and accessories of wagons	276	8630	342246
3746	Manufacture of automobile parts	367	12934	796853
3761	Manufacture of bicycles and frames	82	847	70973
3762	Manufacture of cycle rickshaws	92	115	27964

3.0 Field visits to some selected industry clusters

To generate some additional information with regard to the state of affairs prevalent in different industry subsectors, field visits were undertaken to some selected clusters, the details of which are presented below.

3.1 Foundry cluster at Howrah (West Bengal)

In the Howrah district, the total number of registered small scale foundry units are around 450 with the biggest agglomeration in the Belgachia area. A visit to the cluster revealed a low level of awareness with regard to energy conservation. The foundry cluster at Howrah is more than 100 years old and majority of the owners have very little knowledge of foundry technology. There is no systematic monitoring of either the coke consumption or the furnace operating parameters. Most of the units have never measured the melt temperature and has no idea as to how much this temperature should be. The most commonly encountered size of the furnace is 48" and the average coke ratio ranges from 1:3 to 1:4, which is a very high figure.

Of the 450 foundry units, all are of conventional design and there are no divided blast cupolas in the region. The foundry units at Howrah were set up primarily to provide support services to the jute industry in the area. But with the gradual industrial recession in the region, the load on these units have reduced considerably over the years resulting in a sharp drop in the capacity utilisation of these furnaces. The total annual coal consumption in the belt is estimated at 1,50,000 MT.

The foundry owners are, however, quite receptive to suggestions/technical assistance from outside organisations with regard to reduction in coke ratio. The entrepreneurs are also willing to undertake demonstration projects provided it offers a cost effective solution to reduce the coke consumption in the furnaces.

3.2 Pottery industry - Khurja (U.P)

The pottery industry in Khurja consists of around 515 units engaged in the manufacture of crockeries, insulators, bone chinaware, sanitary and decorative items. There are about 500 downdraft kilns with sizes ranging from 14' - 22'. Average batch time for these kilns is between 10-15 days and are fired once in a month. The total number of shuttle kilns is 15 and these are fired 2-3 times a month. Coal is the major source of energy used by the

industry, with an estimated annual consumption of 80,000 MT. The design of the downdraft kilns are very old and there is a significant scope for reducing the coal consumption in the kilns. The possibility of using kilns that can operate on natural gas also needs a detailed investigation as the Khurja cluster is not very far from the HBJ gas pipeline. The problems highlighted by the industry owners mainly related to non-availability of sufficient quantity of good quality coal.

3.3 Lock industry - Aligarh

The lock industry cluster at Aligarh consists of approximately 3000 units. Eighty units have complete manufacturing facility while the remaining ones are engaged in some selective operations in the lock manufacturing process chain. Electricity is the major source of energy used in these units. HSD and coke is also used, but to a limited extent (primarily in the diecasting units). The lock cluster is not very energy intensive but offers scope with regard to product quality upgradation/introduction of new product ranges. Aligarh lock industry has been included in the 13 industry clusters identified by SIDBI under their cluster modernisation programme. The major problem faced by the industry is with regard to unreliable power supply from the State Electricity Board.

4.0 Conclusion

The small scale industry presents an ideal case where substantial scope for improving the energy efficiency exists through technological upgradation. The level of awareness with regard to energy conservation is low and the systems/equipments employed are of outmoded design. The apathy on the part of majority of the industry owners to upgrade the technology level is clearly reflected on poor product quality one hand to high inefficiency on the other. The entrepreneurs who are interested in improving the efficiency/system performance are constrained by lack of technical knowhow and are also not able to hire the services of consultants. It is felt that one of the possible ways to improve the end use energy efficiency in the SSI's is to undertake demonstration projects in some energy intensive clusters.

In addition to the detailed energy analysis of the foundry cluster at Agra and the glass industry at Firozabad, which are covered under the present study, the additional clusters in which attention can be focussed are shown in **Figures 1 through 3**. The locations marked in the above figures represent energy intensive clusters under **casting and forging industry, edible oil & fat industry and clay tile industry**.

The cost of retrofitting or modernisation to be incurred for the initial demonstration projects may be provided as a grant or soft loan by financial institutions or banks like SBI, SIDBI, etc., under the programmes initiated by them to promote industrial energy conservation. It is felt that successful demonstration of newer technology options in one/two units will instill the necessary confidence in the minds of the entrepreneurs within that cluster and motivate them to undertake similar projects. Once the industry owners are convinced of the benefits of energy conservation measure by these actual implementation projects, the process of change, it is felt, will become self sustaining without requiring any further financial assistance from outside agencies.

Volume 2

Energy audit
in
Agra foundry cluster

CONTENTS

Chapter 1

Introduction 1 - 2

Chapter 2

Energy audit of divided blast cupola 3 - 13

Chapter 3

Energy audit of conventional cupola 14 - 22

Chapter 4

Analysis of test results and recommendations 23 - 26

Chapter 5

Conclusion 27 - 30

Introduction

The cupola based foundries at Agra were identified as one of the clusters to be covered in detail under the present energy sector study. There are about 200 foundries in the cluster registered under the small scale sector. The furnaces are of conventional type with only a small percentage employing the divided blast operation. Most of the units operate twice a week with a melting campaign of 6-8 hours duration. A rough break-up of the size distribution of the cupolas in the region is given below.

Less than 3 tph rating	-	40%
Between 3-6 tph rating	-	50%
Above 6 tph rating	-	10%

Coke is the primary source of energy in the cupola to melt the metallics in the form of pig-iron, cast iron and steel scrap. The average coke feed rate (coke consumed per tonne of molten metal) of these furnaces were reported to be in the range of 1:4, which is a very high figure. Apart from poor energy efficiency, another problem area for these units is related to the pollution aspect. Due to proximity of the foundry cluster to the Taj, the entire area has been declared as a sensitive zone and the foundry owners are forced to put up flue gas cleaning system to comply with the stack emission standards laid down by the state pollution control board.

Under the present study, energy audit of two representative units were carried out. The melting efficiency of the cupolas were evaluated by quantifying various losses associated with the cupola operation. One unit employing conventional cupola and the other employing a divided blast cupola were selected for the audit study. The process steps employed in a foundry unit are shown **figure 1.1**. In order to compute the heat balance, the entire sequence of events, starting from the bed preparation to furnace drop out was monitored closely so as to quantify the coke feed rate and other relevant parameters. Although the electrical load constitutes only a small share of the total energy use, the audit of electrical motors (used for blowers) was also undertaken as part of the exercise.

The results of the energy audit study carried out in the cupolas, the analysis of the test results and the major areas identified for improving the furnace efficiency are detailed in the following chapters.

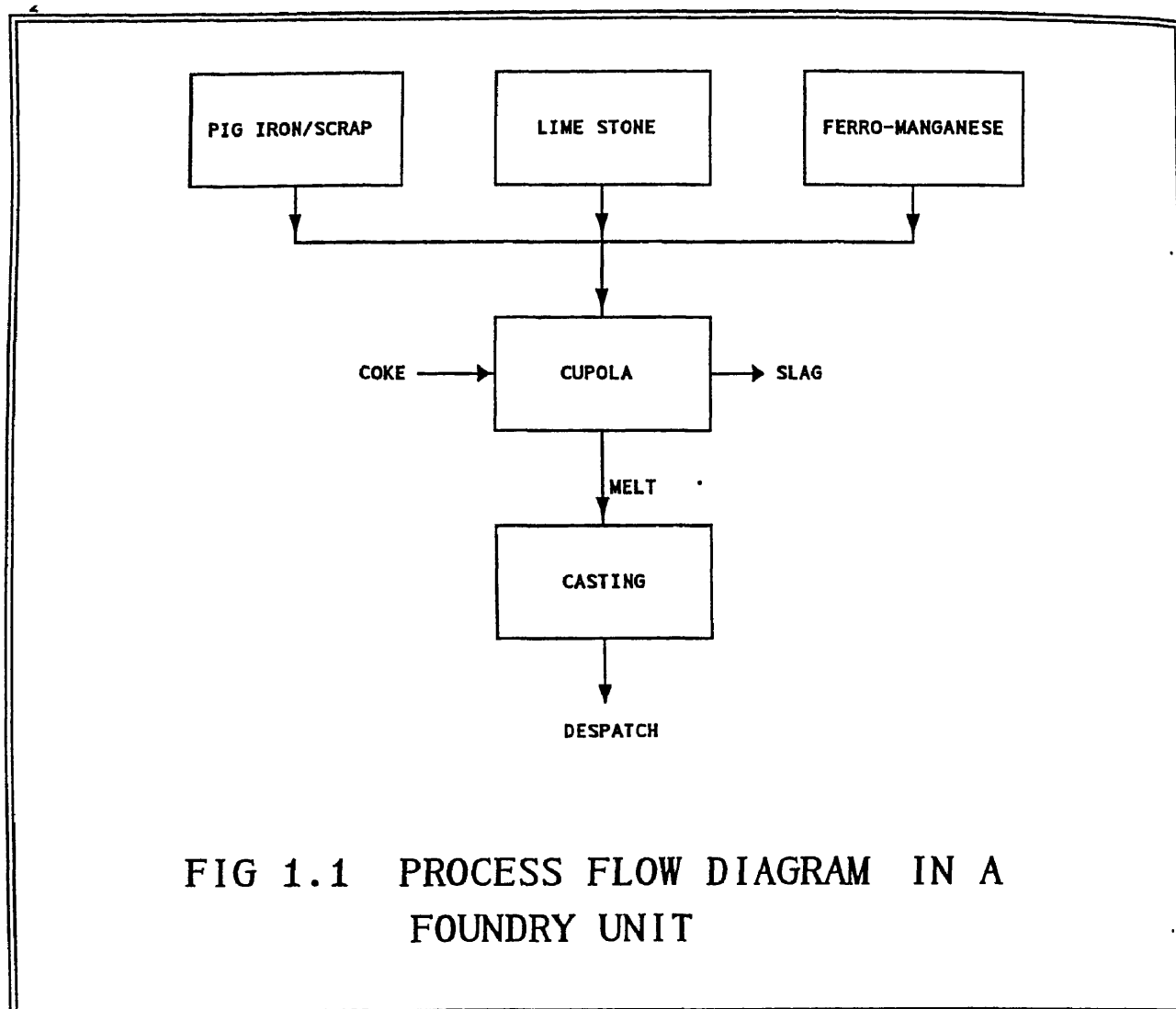


FIG 1.1 PROCESS FLOW DIAGRAM IN A
FOUNDRY UNIT

Energy audit of divided blast cupola (DBC)

The unit covered under the study employing DBC for the melting process manufactures pipes and pipe fittings, manhole covers, etc. The furnace has a melting zone diameter of 48". A schematic diagram of DBC is shown in **figure 2.1**. The entire sequence of melting, starting from bed coke preparation to furnace drop out was monitored for the purpose of carrying out the heat balance of cupola and is presented below.

2.1 Heat balance of divided blast cupola

The timings of some key events in the melting sequence is shown in **table 2.1**. The various measurements taken and the compilation of different heat components associated with furnace operation is detailed below. The analysis of coke, cast iron scrap, cast iron component, slag and lime stone are given in **annexure 1**.

Table 2.1. Sequence of key events

Time of firing	3.30 AM
Time of blower on	7.00 AM
Time of first tap	8.03 AM
Time of last charge	4.45 PM
Time at which blower is switched off	5.25 PM
Furnace drop out	5.30 PM

Computation of heat balance

Metal charge	=	61,317 kg
Coke charge	=	11,618 kg
Limestone charge	=	2100 kg
Ferro-manganese charge	=	140 kg
Number of hours of melting campaign	=	10.5 hr
Melting rate	=	5840 kg/hr
Coke burning rate	=	1106 kg/hr
Limestone charge rate	=	200 kg/hr
Ferro-manganese charge rate	=	13.3 kg/hr

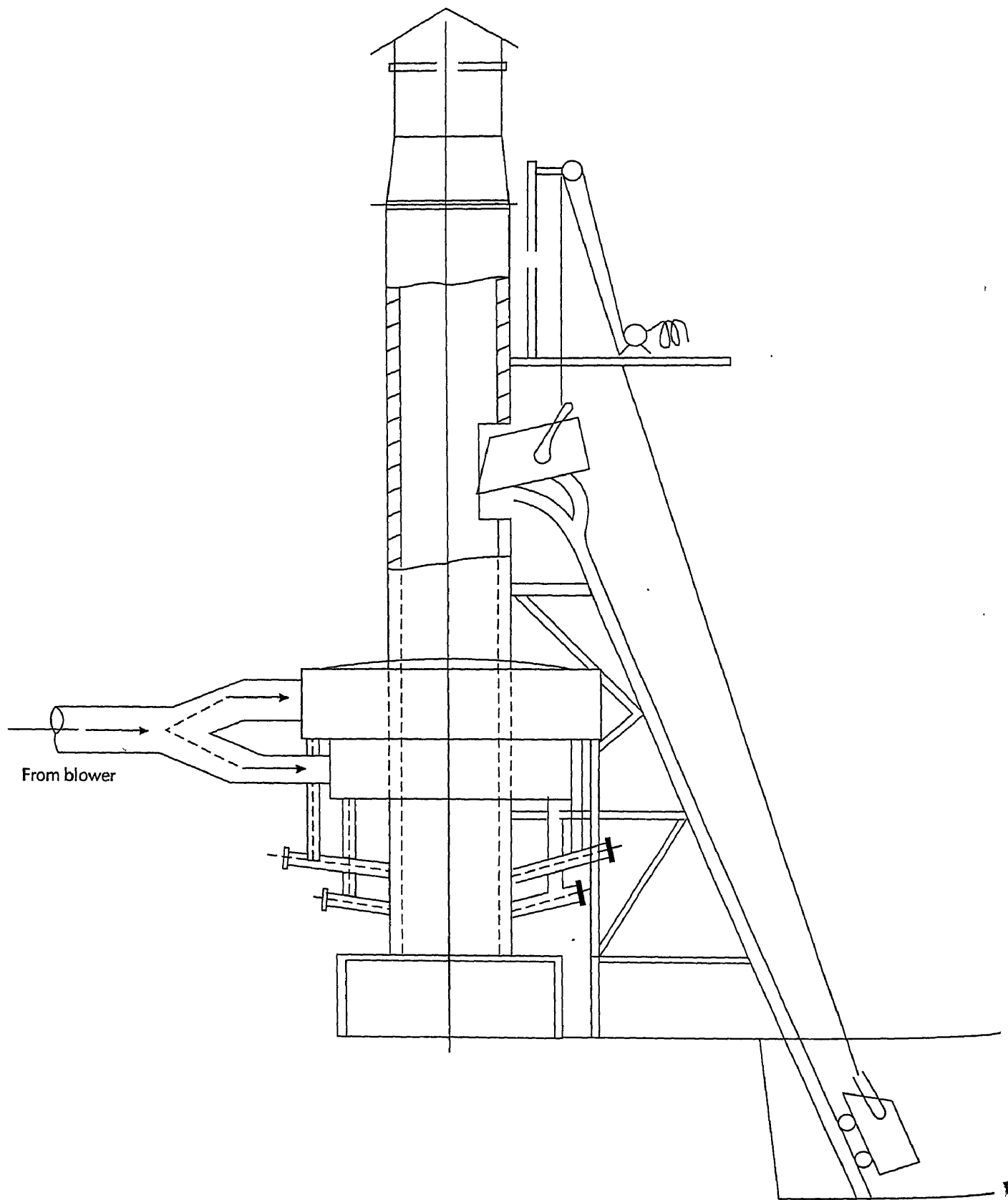


Fig 2.1 divided blast cupola (DBC)

Carbon content of iron charged	=	3.49%
Silicon content of iron charged	=	1.94%
Manganese content of iron charged	=	0.62%
Carbon content of iron tapped	=	4.05%
Silicon content of iron tapped	=	1.12%
Manganese content of iron tapped	=	0.44%
Fixed carbon in coke	=	67.32%
CaCO ₃ content of limestone	=	96.43%
CaO content of slag	=	25.50%
FeO content of slag	=	2.84%
CO ₂ in flue gas	=	13.0%
CO in flue gas	=	14.0%
Ambient dry bulb temperature	=	39 °C
Ambient wet bulb temperature	=	29 °C
Temperature of melt	=	1405 °C
Temperature of flue gas	=	560 °C

Heat input

(a) Combustion of coke

Total fixed carbon in coke	=	745 kg/hr
Heat content of carbon	=	7831 kcal/kg
Total heat input	=	58,33,007 kcal/hr
Loss of carbon to iron	=	32.7 kg/hr
Moles of carbon loss to melt	=	2.72 kmol/hr
Net weight of carbon burnt	=	712 kg/hr
Net moles of carbon burnt	=	59.3 kmol/hr

(b) Oxidation

Total CaCO ₃ in limestone	=	193 kg/hr
Moles of CaCO ₃ charged per hour	=	1.93 kmol/hr

Weight of CaO in slag	=	108 kg/hr
Weight of slag formed	=	424 kg/hr
Weight of FeO in slag	=	12 kg/hr
Heat of formation of FeO	=	895 kcal/kg
Heat produced by oxidation of Fe ($\text{Fe} + \frac{1}{2}\text{O}_2 \rightarrow \text{FeO} + \text{heat}$)	=	10,770 kcal/hr
Percentage silicon oxidised	=	0.82%
Weight of silicon oxidised	=	47.9 kg/hr
Heat of formation of SiO_2	=	3418 kcal/kg
Heat produced by oxidation of silicon ($\text{Si} + \text{O}_2 \rightarrow \text{SiO}_2 + \text{heat}$)	=	1,63,683 kcal/hr
Percentage manganese oxidised	=	0.18%
Weight of manganese oxidised	=	10.5 kg/hr
Heat of formation of MnO	=	1297 kcal/kg
Heat produced by oxidation of manganese ($\text{Mn} + \frac{1}{2}\text{O}_2 \rightarrow \text{MnO} + \text{heat}$)	=	13,634 kcal/hr
Heat input from oxidation reactions	=	1,88,087 kcal/hr

(c) Sensible heat in air blast

(i) Flue gas generation

CO_2 = 13.0%	
CO = 14.0%	
N_2 = 73.0%	
Weight of CaCO_3 charged	= 193 kg/hr
Moles of CaCO_3 charged	= 1.93 kmol/hr
Moles of carbon in CaCO_3 charged	= 1.93 kmol/hr
Total moles of carbon in coke burnt	= 59.3 kmol/hr
Total moles of carbon forming CO & CO_2	= 61.2 kmol/hr
Percentage moles of carbon from CaCO_3	= 3.15%
Moles of carbon in one mole flue gas	= 0.27 mol
Moles of carbon in flue gas from CaCO_3	= 0.008 kmol/hr
Moles of carbon in flue gas from coke	= 0.262 kmol/hr

Weight of carbon per mole of flue gas (This excludes carbon in CaCO_3)	=	3.14 kg/mol flue gas
Total carbon burnt	=	712 kg/hr
Quantity of flue gas generated	=	226.8 kmol/hr

(ii) Blast air requirement

Moles of CO_2 in flue gas	=	29.5 kmol/hr
Molecular weight of CO_2	=	44.01 kg/kmol
Weight of CO_2 in flue gas	=	1297 kg/hr
Moles of CO in flue gas	=	31.8 kmol/hr
Molecular weight of CO	=	28.01 kg/kmol
Weight of CO in flue gas	=	889.2 kg/hr
Moles of N_2 in flue gas	=	165.53 kmol/hr
Molecular weight of N_2	=	28.02 kg/kmol
Weight of N_2 in flue gas	=	4637 kg/hr
Oxygen requirement for CO_2	=	29.48 kmol/hr
Oxygen requirement for CO	=	15.87 kmol/hr
Oxygen requirement for FeO formation	=	0.08 kmol/hr
Oxygen requirement for SiO_2 formation	=	1.70 kmol/hr
Oxygen requirement for MnO formation	=	0.19 kmol/hr
Total oxygen requirement	=	47.33 kmol/hr
	=	1515 kg/hr
Blast air requirement	=	225.38 kmol/hr
	=	6503 kg/hr
Moisture in air	=	0.029 mol/mol air
Total moisture in blast air	=	118 kg/hr
Temperature of air blast	=	39°C

The summary of heat input to the cupola is given in table 2.2.

Table 2.2. Summary of heat input

Type	Heat input (kcal/hr)	Percentage heat (%)
Potential heat in coke	58,33,007	96.9
Heat of oxidation of Fe	10,770	0.2
Heat of oxidation of Si	1,63,683	2.7
Heat of oxidation of Mn	13,634	0.2
Total heat input	60,21,194	100.0

Heat output

Iron charge rate	=	5840 kg/hr
Weight of FeO in slag	=	12 kg/hr
Weight of Fe oxidised to FeO	=	9.4 kg/hr
Iron tapped	=	5830 kg/hr
Temperature of iron charged	=	39 °C
Temperature of iron tapped	=	1405 °C
Melting point of iron	=	1350 °C
Mean specific heat of iron	=	0.18 kcal/kgK
Sensible heat in iron melt	=	13,75,848 kcal/hr
Latent heat of fusion of iron	=	66 kcal/kg
Latent heat in iron melt	=	3,82,079 kcal/hr
Superheat temperature of iron melt	=	55 °C
Superheat in iron melt	=	64,134 kcal/hr
Total heat content of iron melt	=	18,22,061 kcal/hr
Weight of limestone charged	=	200 kg/hr
CaCO ₃ content of limestone	=	96.43%
Weight of CaCO ₃ charged	=	193 kg/hr
Heat of decomposition of CaCO ₃	=	424.6 kcal/kg
Total heat of decomposition of limestone	=	81,888 kcal/hr
Heat of slagging reaction	=	210 kcal/kg CaCO ₃
Total heat of slagging reaction	=	40,501 kcal/hr
Weight of slag formed	=	423.8 kg/hr
Mean specific heat of slag	=	0.321 kcal/kgK
Heat content of molten slag	=	1,85,755 kcal/hr
Net heat required for slag	=	1,45,254 kcal/hr

Flue gas generation

CO ₂	=	1297 kg/hr
CO	=	889 kg/hr
N ₂	=	4637 kg/hr
H ₂ O	=	118 kg/hr

Temperature of flue gases	=	560 °C
Mean specific heat of CO ₂	=	0.249 kcal/kgK
Mean specific heat of CO	=	0.260 kcal/kgK
Mean specific heat of N ₂	=	0.258 kcal/kgK
Mean specific heat of H ₂ O	=	0.481 kcal/kgK
Heat content of CO ₂	=	1,68,146 kcal/hr
Heat content of CO	=	1,20,626 kcal/hr
Heat content of N ₂	=	6,23,721 kcal/hr
Heat content of H ₂ O	=	29,513 kcal/hr
<i>Total heat content of flue gases</i>	=	<i>9,42,006 kcal/hr</i>

Heat loss due to CO in flue gas

Weight of CO in flue gas	=	889 kg/hr
Heat of combustion of CO	=	2414.7 kcal/kg
Total heat of combustion of CO	=	21,47,122 kcal/hr
Melt to coke ratio	=	5.28 kg/kg

The summary heat balance is furnished in **table 2.3**. A sankey diagram showing various heat components is given in **figure 2.2**.

Table 2.3. Summary of heat balance of DBC

Heat component	Heat output (kcal/hr)	Percentage heat (%)
Heat in melt	18,22,061	30.3
Heat of calcination of limestone	81,888	1.4
Heat in slag	1,45,254	2.4
Sensible heat in flue gas	9,42,006	15.6
Heat of combustion of CO	21,47,122	35.7
Structural losses	8,82,863	14.7
Total heat output	60,21,194	100.0

2.2 Electrical energy audit

The unit receives power at 11 kV from the Uttar Pradesh State Electricity Board (UPSEB) which is stepped down to 440 V. The total connected load of the unit is 73 kW. The major load of electricity consumption is electric motors which constitute 60% (44 kW) of the total connected load.

10

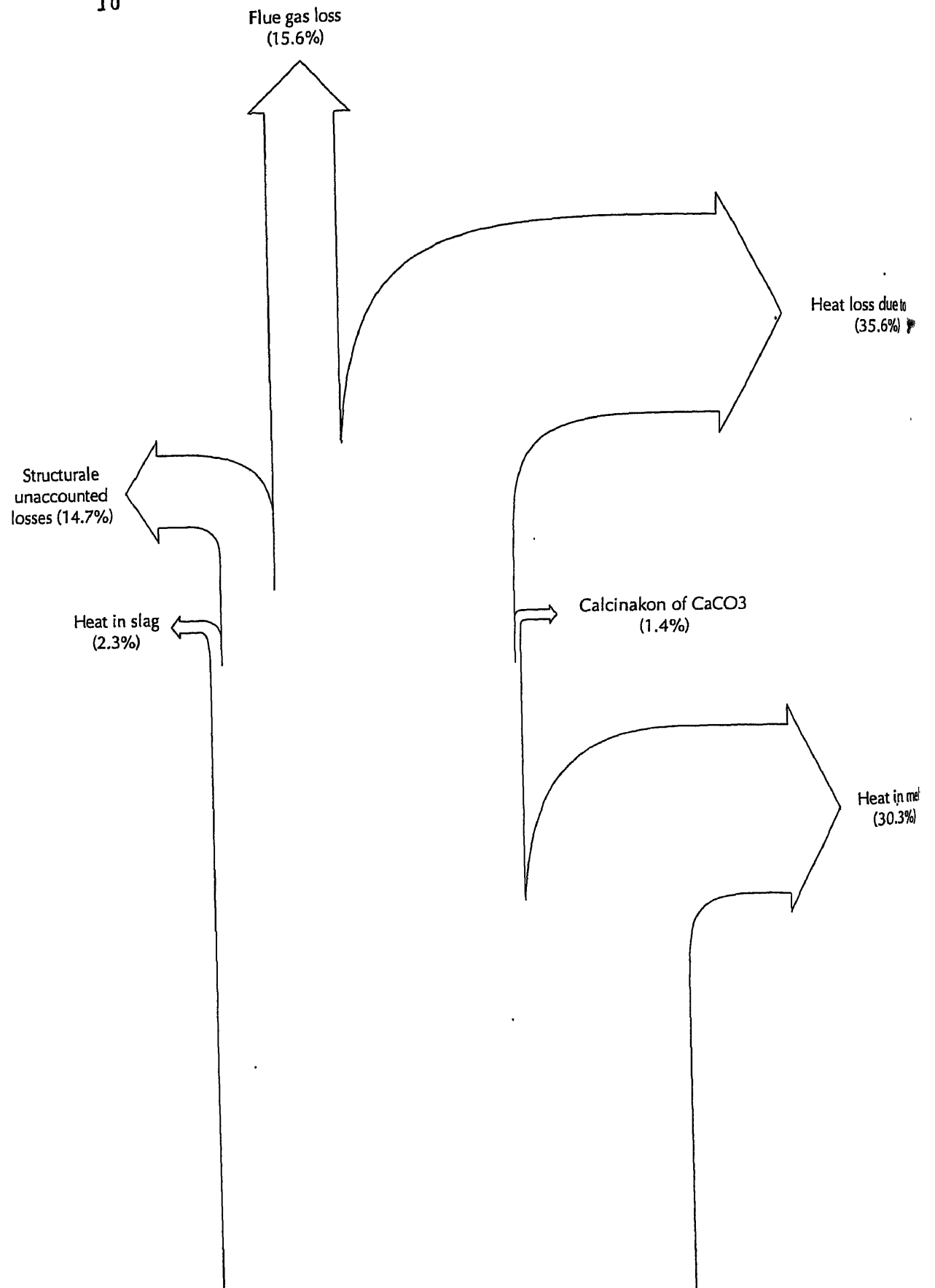


Fig 2.2 Heat balance - Divided blast cupola

Electricity is billed every month based on the energy consumption and maximum demand during the billing period. The electricity tariff is Rs 1.45 per kWh and Rs 28 per kW of maximum demand. The monthly electricity bill of the unit is in the range of Rs 10,000 to 12,000.

2.2.1 Electric motor

The major loads of the plant are blower and I.D. fan motors. Three phase slip ring induction motors are used for both. In order to evaluate the motor performance, load test was carried out on both the motors. Care was taken to record the peak load of the motors to decide their extent of loading. The measurement details of the motors are given in table 2.4.

Table 2.4. Field testing of motors

Drive	Rated power (kW)	Rated current (Amp)	Actual current (Amp)	Power loading (%)	Power factor (%)
Blower	22	40	42.8	101.5	0.89
I.D. fan	22	40	30.0	62.0	0.80

To achieve the best design efficiency and power factor values, motors should be loaded in the range of 70-90% of their rated capacity. As can be seen from the table 2.4, the I.D. fan motor was operating at 62% of its rated capacity and is slightly oversized for its application. Economics were worked out for the replacement of 22 kW blower by a slip ring of 18.5 kW rating. The analysis showed a payback period of more than 10 years which is very high and is attributable to low operating hours of this motor coupled with relatively higher investment associated with slip ring motors. Therefore, it is not advisable to replace the 22 kW blower motor with a motor of lower rating.

It could also be seen from table 2.4 that blower motor is operating in excess of its rated capacity (operating at more than 100% of rated load). Care has to be taken to prevent further possible loading by way of better maintenance practices. Frequent start/stop, harmonics or transient voltages and current, etc. may damage the motor or the equipment and may also pose safety hazards to the operating personnel.

2.2.2 Power factor

The average power factor of the plant is maintained at about 0.85. Capacitor banks of 32 kVAR capacity have been installed on the main bus-bar for improving the power factor. It is evident that the overall power factor of the plant is quite low and efforts should be made to improve it to 0.95. The economics of such a scheme is given below.

Present maximum demand	=	70 kVA
Present power factor	=	0.85
Desired power factor	=	0.95
Additional capacitors required	=	18 kVAR
Investment for capacitor banks (@ Rs 350 per KVAR)	=	Rs 6,300
Reduction in maximum demand	=	7 kVA
Annual saving in demand charges (@ Rs 51 per kW)	=	Rs 3,589
Simple payback period	=	1.8 years

It could be seen that a total investment of Rs 6,300 is required to improve the power factor value to a desired level of 0.95 and the payback period would be less than 2 years. It may, however, be noted that these savings would be realised only when the contract demand of the plant is lowered by 7 kVA.

2.3 Compensation scheme

It was found that all the capacitor banks have been installed at main bus-bar and remain in the circuit even after both the motors (major inductive load) are switched off. This type of arrangement may lead to over compensation when large inductive load is switched off. It is recommended that power factor compensation should be provided at two locations; compensation at motor terminals and compensation at motor control centre. This type of compensation scheme has advantage that at distribution centres only base load is compensated and does not lead to over compensation when motors are switched off. Additional compensation from capacitors comes into the circuit only when extra inductive loads in the form of induction motors come into the circuit.

Measurements were taken on both the motors to identify the correct size of capacitors to be connected on their terminals. **Table 2.5** gives the results of the test carried out on both the motors.

Table 2.5. Capacitors requirement for motor terminals

Drive	Rated power (kW)	Actual power drawn (kW)	Present power factor of the motor	Proposed kVAR	Improved power factor
Blower	22	25.1	0.89	4.6	0.95
I.D. Fan	22	15.9	0.80	6.5	0.95

As can be seen from table 2.5, about 10 kVAR is required to compensate for the inductive load of motors. Care should be taken to instal these capacitors through motor starters so that they come into circuit only when motors are switched on. These motors should also be properly marked for safety reasons. The overall/best power factor improvement scheme, therefore, would be to connect about 8 kVAR at the main bus and 4 and 6 kVAR at blower and I.D. fan motor terminals respectively. **Annexure 2** highlights the use of optimum blower volume & pressure, use of capacitor banks for power factor improvement and proper maintenance of blower systems.

Energy audit of conventional cupola

The unit selected for the study employs a 42" conventional cupola. A schematic diagram of conventional cupola is shown in figure 3.1. For the purpose of computing the energy balance, the entire sequence of the melting campaign was monitored. The timings of some key events in the melting sequence is shown in table 3.1.

Table 3.1. Sequence of key events

Time of firing	6.15 AM
Time of blower on	8.57 AM
Time of first tap	10.06 AM
Time of last charge	6.15 PM
Time at which blower is switched off	7.02 PM
Furnace dropout	7.10 PM

The various measurements taken and the computation of the heat balance of the cupola are detailed below.

Metal charge	=	34,500 kg
Coke charge	=	10,950 kg
Limestone charge	=	1485 kg
Ferro-manganese charge	=	60 kg
Number of hours of melting campaign	=	10 hr
Melting rate	=	3450 kg/hr
Coke burning rate	=	1095 kg/hr
Limestone charge rate	=	148.5 kg/hr
Ferro-manganese charge rate	=	6.0 kg/hr
Carbon content of iron charged	=	3.49%
Silicon content of iron charged	=	1.94%
Manganese content of iron charged	=	0.62%
Carbon content of iron tapped	=	3.90%
Silicon content of iron tapped	=	1.12%
Manganese content of iron tapped	=	0.44%

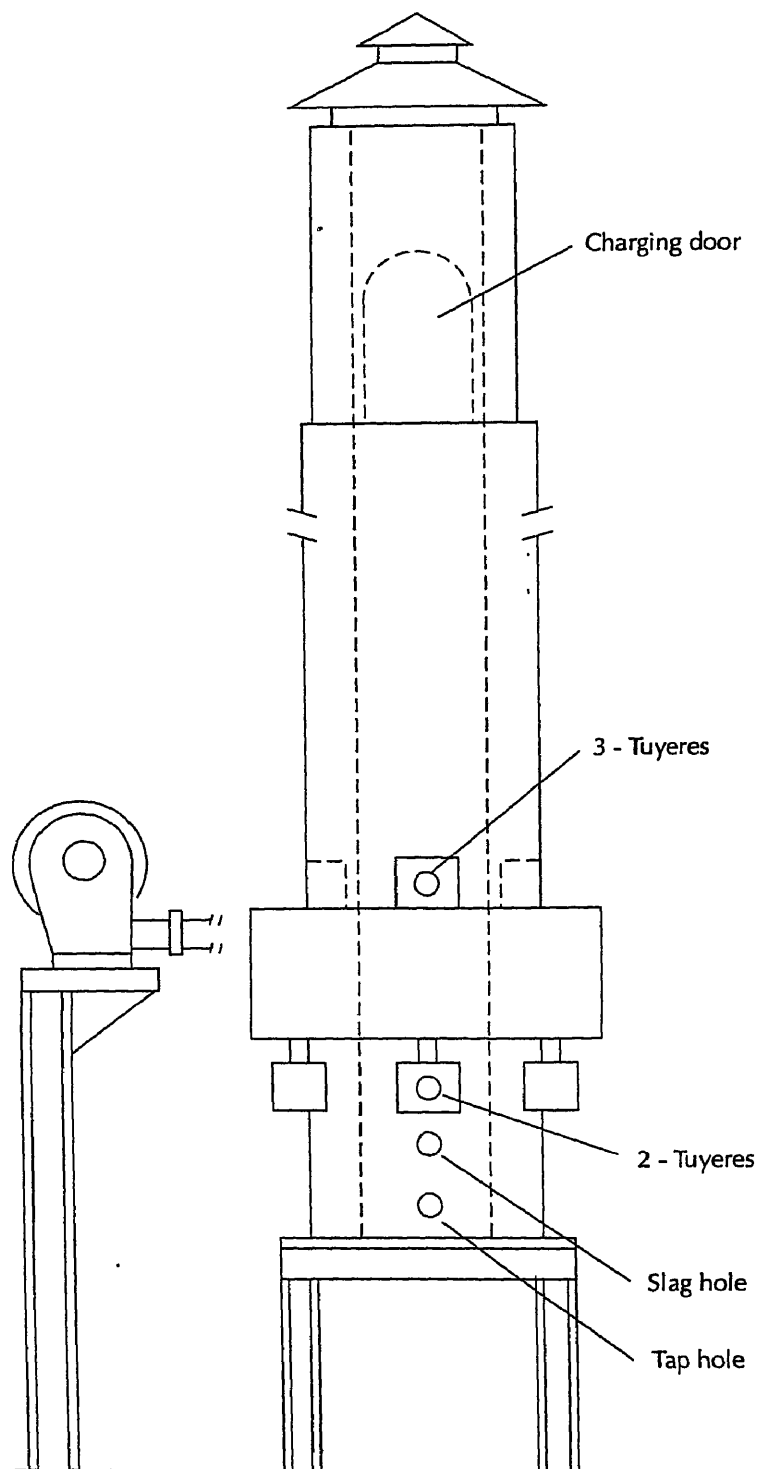


Fig. 3.1 Conventional cupola

Fixed carbon in coke	=	67.32%
CaCO ₃ content of limestone	=	96.43%
CaO content of slag	=	25.50%
FeO content of slag	=	2.84%

CO ₂ in flue gases	=	13.0%
CO in flue gases	=	14.0%

Dry bulb temperature	=	37 °C
Wet bulb temperature	=	28 °C
Temperature of melt	=	1380 °C
Temperature of flue gas	=	500 °C

Heat input*(a) Combustion of coke*

Total fixed carbon in coke	=	737 kg/hr
Heat content of carbon	=	7831 kcal/kg
Total heat input	=	57,72,757 kcal/hr
Loss of carbon to iron	=	14.1 kg/hr
Moles of carbon loss to melt	=	1.18 kmol/hr
Net weight of carbon burnt	=	723 kg/hr
Net moles of carbon burnt	=	60.2 kmol/hr

(b) Oxidation

Total CaCO ₃ in limestone	=	143 kg/hr
Moles of CaCO ₃ charged per hour	=	1.43 kmol/hr
Weight of CaO in slag	=	80.2 kg/hr
Weight of slag formed	=	315 kg/hr
Weight of FeO in slag	=	8.9 kg/hr
Heat of formation of FeO	=	895 kcal/kg
Heat produced by oxidation of Fe	=	7997 kcal/hr
(Fe + ½O ₂ ----> FeO + heat)		

Silicon oxidised	=	0.82 %
Weight of silicon oxidised	=	28.3 kg/hr
Heat of formation of SiO_2	=	3418 kcal/kg
Heat produced by oxidation of silicon ($\text{Si} + \text{O}_2 \rightarrow \text{SiO}_2 + \text{heat}$)	=	96,701 kcal/hr

Manganese oxidised	=	0.18 %
Weight of manganese oxidised	=	6.2 kg/hr
Heat of formation of MnO	=	1297 kcal/kg
Heat produced by oxidation of manganese ($\text{Mn} + \frac{1}{2}\text{O}_2 \rightarrow \text{MnO} + \text{heat}$)	=	8055 kcal/hr
Heat input from oxidation reactions	=	1,12,753 kcal/hr

(c) *Sensible heat in air blast*

(i) *Flue gas generation*

CO_2	=	13.2%
CO	=	13.5%
N_2	=	73.3%
Weight of CaCO_3 charged	=	143 kg/hr
Moles of CaCO_3 charged	=	1.43 kmol/hr
Moles of carbon in CaCO_3 charged	=	1.43 kmol/hr
Total moles of carbon in coke burnt	=	60.20 kmol/hr
Total moles of carbon forming CO & CO_2	=	61.63 kmol/hr
Percentage moles of carbon from CaCO_3	=	2.32 %
Moles of carbon in one mole flue gas	=	0.267 mol
Moles of carbon in flue gas from CaCO_3	=	0.006 kmol/hr
Moles of carbon in flue gas from coke	=	0.261 kmol/hr
Weight of carbon (This excludes carbon in CaCO_3)	=	3.13 kg/mol flue gas
Total carbon burnt	=	723 kg/hr
Quantity of flue gas generated	=	230.8 kmol/hr

(ii) *Blast air requirement*

Moles of CO_2 in flue gas	=	30.47 kmol/hr
Weight of CO_2	=	1341 kg/hr

Moles of CO in flue gas	=	31.16 kmol/hr
Weight of CO	=	872.8 kg/hr
Moles of N ₂ in flue gas	=	169.20 kmol/hr
Weight of N ₂	=	4740 kg/hr
Oxygen requirement for CO ₂	=	30.47 kmol/hr
Oxygen requirement for CO	=	15.58 kmol/hr
Oxygen requirement for FeO formation	=	0.06 kmol/hr
Oxygen requirement for SiO ₂ formation	=	1.01 kmol/hr
Oxygen requirement for MnO formation	=	0.11 kmol/hr
Total oxygen requirement	=	47.23 kmol/hr
	=	1511 kg/hr
Blast air requirement	=	224.9 kmol/hr
	=	6490 kg/hr
Moisture in air	=	0.03 mol/mol air
Total moisture in blast air	=	122 kg/hr
Temperature of air blast	=	37 °C

The summary of heat input is shown in table 3.2.

Table 3.2. Summary of heat input

Type of heat input	Heat input (kcal/hr)	Percentage heat (%)
Potential heat in coke	57,72,757	98.1
Heat of oxidation of Fe	7,997	0.2
Heat of oxidation of Si	96,701	1.6
Heat of oxidation of Mn	8,055	0.1
Total heat input	82,59,197	100.0

Heat output

Iron charged	=	3450 kg/hr
Weight of FeO in slag	=	8.9 kg/hr
Weight of Fe oxidised to FeO	=	6.9 kg/hr
Iron tapped	=	3443 kg/hr
Temperature of iron charged	=	37 °C
Temperature of iron tapped	=	1380 °C
Melting point of iron	=	1350 °C

Mean specific heat of iron	=	0.18 kcal/kgK
Sensible heat in iron melt	=	8,13,731 kcal/hr
Latent heat of fusion of iron	=	66 kcal/kg
Latent heat in iron melt	=	2,25,633 kcal/hr
Superheat temperature of iron melt	=	30 °C
Superheat in iron melt	=	20,658 kcal/hr
<i>Total heat content of iron melt</i>	=	<i>10,60,022 kcal/hr</i>
Weight of limestone charged	=	148.5 kg/hr
CaCO ₃ content of limestone	=	96.43%
Weight of CaCO ₃ charged	=	143.2 kg/hr
Heat of decomposition of CaCO ₃	=	424.6 kcal/kg
<i>Total heat of decomposition of limestone</i>	=	<i>60802 kcal/hr</i>
Heat of slagging reaction	=	210 kcal/kg CaCO ₃
Total heat of slagging reaction	=	30072 kcal/hr
Weight of slag formed	=	314.6 kg/hr
Mean specific heat of slag	=	0.3209 kcal/kg-°K
Heat content of molten slag	=	1,35,601 kcal/hr
<i>Net heat required for slag</i>	=	<i>1,05,529 kcal/hr</i>
<i>Flue gas generation</i>		
CO ₂	=	1341 kg/hr
CO	=	873 kg/hr
N ₂	=	4740 kg/hr
H ₂ O	=	122 kg/hr
Temperature of flue gas	=	500 °C
Mean specific heat of CO ₂	=	0.245 kcal/kg-°K
Mean specific heat of CO	=	0.259 kcal/kg-°K
Mean specific heat of N ₂	=	0.257 kcal/kg-°K
Mean specific heat of H ₂ O	=	0.476 kcal/kg-°K
Heat content of CO ₂	=	1,51,914 kcal/hr
Heat content of CO	=	1,04,569 kcal/hr
Heat content of N ₂	=	5,63,409 kcal/hr

Heat content of H ₂ O	=	26,815 kcal/hr
Total heat content of flue gas	=	8,46,706 kcal/hr

Heat loss due to CO formation in flue gas

Weight of CO in flue gas	=	873 kg/hr
Heat of combustion of CO	=	2414.7 kcal/kg
Total heat of combustion of CO	=	21,07,668 kcal/hr
Melt to coke ratio	=	3.15 kg/kg

The summary of heat balance is furnished in **table 3.3** and a sankey diagram is given in **figure 3.2**. Various factors affecting the operation of conventional cupolas are given in **annexure 3**. The different types of emission control are given in **annexure 4**.

Table 3.3. Summary of heat balance of the furnace

Heat component	Heat input (kcal/hr)	Percentage heat (%)
Heat in melt	10,60,022	18.0
Calcination of limestone	60,802	1.0
Heat in slag	1,05,529	1.8
Sensible heat in flue gas	8,46,706	14.4
Heat of combustion of CO	21,07,668	35.8
Structural losses	17,04,882	29.0
Total heat output	58,85,609	100.0

3.1 Electrical energy audit

The major load of electricity consumption in the plant is the blower motor of 45 kW. The motor is run by a D.G. set because of non-reliable power supply from UPSEB. In order to evaluate the performance of the motor and to see its loading, load test was conducted on the motor. Care was taken to record the peak load taken by the motor to decide the extent of loading. The measurement details of the motors are given in **table 3.4**.

Table 3.4. Field testing of motors

Drive	Rated power (kW)	Rated current (Amp)	Actual current (Amp)	Percent loading (%)	Power factor of motor
Blower	45	82	72	81.3	0.85

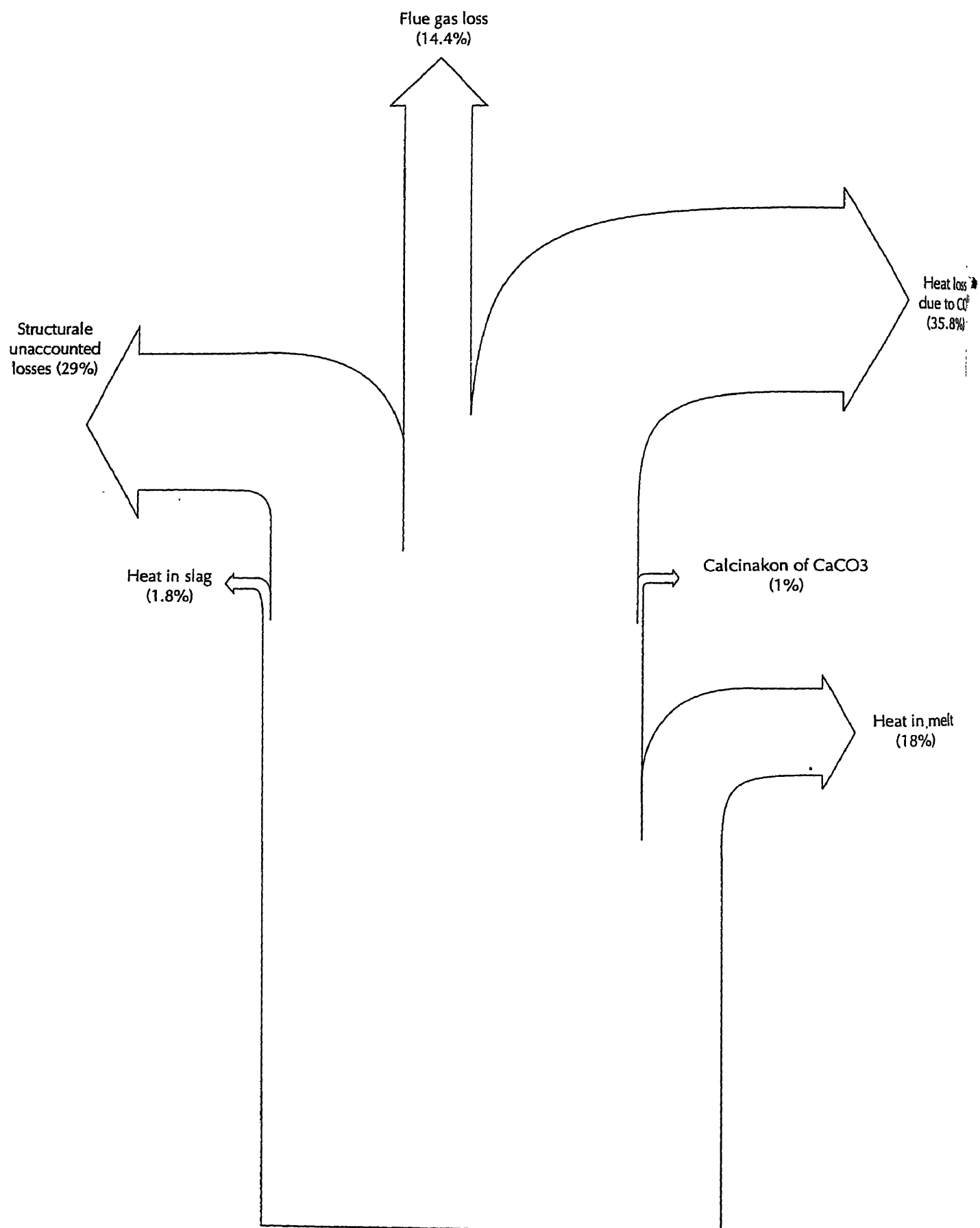


Fig 3.2 Heat balance - Conventional cupola

To achieve the best design efficiency and power factor values, it is recommended that motors should be loaded in the range of 70-90% of their rated capacity. As can be seen from table 3.4, the blower motor is operating at 81.3% of its rated capacity and therefore has been selected correctly as per the load requirement.'

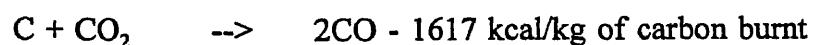
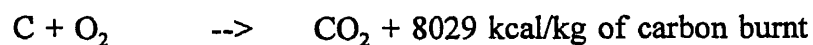
Analysis of test results and recommendations

Based on the energy audit study carried out in the two units, the following recommendations are made to improve the end use energy efficiency. Since there is a lot of commonality in the technology level, degree of mechanisation and operating practices in different units at Agra, the nature of recommendations are by and large similar and the energy conservation measures outlined in this chapter broadly applies to the majority of the foundry units at Agra.

4.1 Divided blast cupola (DBC)

It is strongly recommended to retrofit the conventional cupolas (which account for 90% of the cupola population at Agra) to divided blast operation. The concept of divided blast is an established technique for reducing the specific coke consumption in a cupola. The benefit of divided blast is also clearly reflected in the energy audit study as the coke feed rate for the DBC was found to be 1:5.3 as against a coke feed rate of only 1:3.1 for the conventional cupola. Various benefits of adopting divided blast operation is given in **annexure 5**. The principle behind the DBC and the cost/benefit analysis of retrofitting the conventional cupola covered under the present study to divided blast operation is presented below.

Although many combustion reaction takes place inside a cupola, the two most important ones are the reaction between coke and oxygen and between coke and carbon dioxide.



The second reaction leads to formation of a gasification zone above the tuyeres. The CO formed is maximum at around one metre above the tuyere. Since this reaction is endothermic, a considerable drop in temperature occurs along the gasification zone with a consequent reduction in core temperature. The reduction in CO formation, therefore, can effectively increase the melting efficiency of the furnace and this is precisely what is attempted in DBCs, by introducing a secondary air blast at approximately one metre above the lower tuyere to restrict the gasification reaction. The main advantages associated with divided blast operation are:

- i. Around 25% saving in coke consumption as compared to conventional cupolas. Coke ratio of 1:8 or more is achievable with divided blast operation.
- ii. Increase in tapping temperature by around 50 °C.
- iii. Higher melting rate for the same melt zone diameter.

However, the disadvantage associated with DBC operation is the oxidation of silicon for which ferro-silicon additive becomes essential to avoid chilling of melt.

The overall economics of retrofitting the conventional cupola to divided blast operation is given below for the unit in which energy audit was carried out.

Amount melted per day	=	35 t
Number of days of melting per month	=	8 days
Amount melted per year	=	3360 t
Existing coke ratio	=	1 : 3.1
Annual coke consumption	=	1060 t
Coke saving in DBC	=	25%
Annual coke saving with DBC	=	265 t
Cost of coke per tonne	=	Rs 3700
Annual monetary saving	=	Rs 9.80 lakh

From metallurgical point of view divided blast operation needs additional Fe-Si to be charged with the feed to avoid metal chilling.

Annual consumption of Fe-Si	=	15.2 t
Price of Fe-Si per kg	=	Rs 38
Cost of Fe-Si/annum	=	Rs 5.78 lakh
Net annual savings	=	Rs 4.02 lakh
(Coke saving - additional cost of Fe-Si)		
Approximate cost of retrofitting	=	Rs 50,000

As can be seen from the above analysis, the payback period for the investment works out to 1.5 months, which is extremely attractive.

4.2 Optimising design of the divided blast cupola

For the divided blast cupola, the coke ratio was found to be 1:5.3. Although this is significantly lower than the conventional cupola (for which the coke ratio was found to be 1:3.1), it is felt that further scope exists in improving the efficiency of the furnace. It has been reported in the literature that a properly designed DBC can give a coke ratio of 1:8 or less under Indian conditions. Better optimisation/matching of blast rate, melting zone diameter, tuyere dimensions and shaft height of the furnace is required to exploit fully the advantages associated with divided blast operation.

4.3 Foundry return

Foundry return is the scrap iron circulating within the foundry and is generated mainly through rejected castings. The foundry return was found to be in the range of 15-40% depending on the type of the product cast. This rejection rate is considered to be very high keeping in view the not so stringent quality control procedures followed in these units. Reduction in return significantly improves the overall furnace efficiency and can be achieved through better mould making practices. The high rejection rate is also due to low melt temperature (low degree of superheat) achieved in most of the foundries.

4.4 Wind blast

It was noted that the wind blast is kept constant throughout the melting sequence. For a clean drop, it is recommended to cut the blast by 20%, 10-15 minutes before the end of the operation. This helps melting off and thinning of the slag, giving it better fluidity and not letting it stick even to the bed coke.

4.5 Operating practice

The charging of different raw materials in the cupola is done manually without weighing and it is left entirely to the discretion of the furnace operator. There is no instrumentation in the furnace and even the melt temperature, which is a very critical parameter, is not monitored. It is very important to weigh all the inputs of the charge and to ensure that they are of uniform size so that there is uniform melting, metal flow and the temperature remains stable throughout resulting in minimum rejection due to cold shut, shrinkage, etc.

4.6 Recuperative hot blast cupola

In a recuperative hot blast cupola, the heat in the cupola top gas is utilised to preheat the blast air. The total share of heat carried away by the flue gases (sensible heat + heat loss due to CO in flue gas) was found to be 50.4% and 51.9% for the conventional cupola and divided blast cupola respectively. The hot blast system consists of drawing the top gas and burning the CO content in the gas in a suitable combustion chamber. The gases then pass through a heat exchanger in which the incoming combustion air is heated. The recuperative hot blast is not a new concept and has been in practice since 1940's. In a hot blast cupola, it is possible to heat the blast air to about 500 °C with a consequent reduction in coke consumption by about 35% compared to a cold blast cupola. The recuperative hot blast cupola is, however, an expensive proposition and the economic feasibility of its use in relatively smaller units at Agra needs a more detailed investigation.

4.7 Oxygen enrichment

Oxygen addition to the cupola blast have been used since the early 1930's. On a weight basis, the supplementary oxygen usually varies from 2-4%. Oxygen can be added to blast air or injected through the tuyeres. Oxygen enrichment in cold blast leads to; (i) increased melting rate, (ii) hotter metal at the spout (for each percentage of enrichment, the temperature of the metal at the spout increased by around 5.5°C), (iii) saving of coke and (iv) possibility of replacing pig iron with scrap. Like the recuperative hot blast, oxygen enrichment in cupola is also a relatively new concept for the Indian industry and to study its applicability for the foundry units at Agra, an in-depth analysis is required.

Conclusion

The iron foundry industry at Agra consists of 200 registered cupola based units. In order to identify the scope for energy conservation in the melting furnaces, energy audit was conducted in two representative foundry units; one employing a conventional cupola and the other, a divided blast cupola (DBC). The key findings of the energy audit study are given in table 5.1.

Table 5.1. Key results of the energy audit study

Furnace type	Coke feed rate	Melting efficiency (%)	Tapping temperature (°C)
Conventional blast cupola	1:3.1	18.0	1380
Divided blast cupola	1:5.3	30.3	1405

The following conclusions are drawn from the study:

- (i) Owners were generally "remote" from the production process with no significant technical/ scientific appreciation of the processes used. In most cases, day to day plant operation is controlled by "experienced operators", colloquially known as "Mistris" who have traditionally handed down the craft from father to son. Many of these mistris work for more than one owner. They are considered as expert and not to be questioned on the cupola operation. Most of the mistris are illiterate, have no scientific or technical training and therefore are not able to assess the efficiency of the furnace operation. It is significant that the most effective foundries visited had abandoned the employment of mystries¹.

The apathy on the part of majority of foundry owners to upgrade the technology level is clearly reflected from the fact that out of the 200 registered foundry units in the cluster, only 15 units are employing DBC.

- (ii) The cupola furnaces suffer from gross inefficiency. The energy audit study shows that the coke feed rate for the conventional cupola and DBC were only 1:3.1 and

1:5.3 respectively. Both these figures are high for their respective categories.

- (iii) The quality of coke supplied to the foundries is poor and even so ash content and grading is very variable. Ash content is very high and over 30% (good European coke will have an ash content not higher than 10%). Size of the coke is also very variable and it contains both excessive small sized material (75 mm to dust) and large lumps (over 200 mm). The strength of the coke is also very low leading to serious degradation both in storage and in the cupola¹.

Bad quality coke will depress both the melting rate of the cupola and the attainable metal temperature for a given coke charge and blast rate. Because of the high ash content, the available carbon in the coke will be accordingly low, some of the claims of low coke consumption made by some of the foundries should therefore be treated with circumspection¹.

- (iv) Many of the cupolas are wrongly sized. Optimum performance of the cupolas requires the correct combination of melting zone area, blast volume and blast pressure. The dimensions relating to cupola well depth, tuyere area and shaft height are also significant. These factors apply whether the furnace is of conventional or divided blast design. It is suspected that many of the cupolas seen had too low a blast rate and pressure. Inefficiencies were made worse by the poor design & conditions of blower, blast main, windbelt and tuyere units and also the deteriorated condition of much of this equipment¹.

There is a substantial scope for improving the efficiency of cupola by proper matching of blast rate, tuyere dimension, shaft height and melt zone diameter.

- (v) For a properly designed DBC, coke ratio of 1:8 or even less is achievable. This figure is substantially lower than the coke ratio of 1:5.3 found for the DBC studied.
- (vi) The foundry returns were found to be in the range of 20-40% depending on the type of items cast. This figure is considered high keeping in mind that no stringent quality control procedures are followed by the units. The reduction of foundry return can significantly contribute to energy efficiency, which can be primarily achieved by adopting better mould making practices.

It was unusual to find any formal system for recording production data, e.g. metal & coke charged, castings produced, reject numbers and causes etc. In general, castings were only rejected due to obvious visible defects and little notice was taken of metallurgical or dimensional quality. Quantitative chemical analysis and metallurgical examination of specimens were only observed in one foundry¹.

- (vii) The charging is carried out manually and different raw materials are not weighed before being fed into the furnace. The operation of the cupola depends entirely on the experience and judgement of the operator. All these factors indirectly lead to higher coke consumption in the furnaces.
- (viii) Instrumentation is totally absent and even important parameters like melt temperature are not monitored.

Only two foundries observed were aware of the need for, and using, shop floor techniques for the control of metal quality. Proper temperature measurements, thermal analysis for the determination of carbon/silicon contents and wedge tests for the assessment of chilling tendency are important controls if engineer quality castings are to be produced¹.

Even a simply constructed manometer to indicate variations in blast pressure will enable cupola operating conditions to be monitored and action to be improve melting performance¹.

It should be noted that none of the DBCs in the cluster were fitted with automatic blast control system which would improve the performance further¹.

- (ix) For the conventional cupolas (which constitutes around 90% of the furnace population in the cluster), the best option identified is to retrofit these furnaces to divided blast operation. The cost of retrofitting, which is expected to be around Rs 50000, will be paid back in less than 2 months.
- (x) The hot blast cupola operating in the cluster had the lowest reported coke consumption. It may be worthwhile considering heat recovery methods using simple recuperative equipment i.e. without combustion of the flue gases¹.

1:5.3 respectively. Both these figures are high for their respective categories.

- (iii) The quality of coke supplied to the foundries is poor and even so ash content and grading is very variable. Ash content is very high and over 30% (good European coke will have an ash content not higher than 10%). Size of the coke is also very variable and it contains both excessive small sized material (75 mm to dust) and large lumps (over 200 mm). The strength of the coke is also very low leading to serious degradation both in storage and in the cupola¹.

Bad quality coke will depress both the melting rate of the cupola and the attainable metal temperature for a given coke charge and blast rate. Because of the high ash content, the available carbon in the coke will be accordingly low, some of the claims of low coke consumption made by some of the foundries should therefore be treated with circumspection¹.

- (iv) Many of the cupolas are wrongly sized. Optimum performance of the cupolas requires the correct combination of melting zone area, blast volume and blast pressure. The dimensions relating to cupola well depth, tuyere area and shaft height are also significant. These factors apply whether the furnace is of conventional or divided blast design. It is suspected that many of the cupolas seen had too low a blast rate and pressure. Inefficiencies were made worse by the poor design & conditions of blower, blast main, windbelt and tuyere units and also the deteriorated condition of much of this equipment¹.

There is a substantial scope for improving the efficiency of cupola by proper matching of blast rate, tuyere dimension, shaft height and melt zone diameter.

- (v) For a properly designed DBC, coke ratio of 1:8 or even less is achievable. This figure is substantially lower than the coke ratio of 1:5.3 found for the DBC studied.
- (vi) The foundry returns were found to be in the range of 20-40% depending on the type of items cast. This figure is considered high keeping in mind that no stringent quality control procedures are followed by the units. The reduction of foundry return can significantly contribute to energy efficiency, which can be primarily achieved by adopting better mould making practices.

It was unusual to find any formal system for recording production data, e.g. metal & coke charged, castings produced, reject numbers and causes etc. In general, castings were only rejected due to obvious visible defects and little notice was taken of metallurgical or dimensional quality. Quantitative chemical analysis and metallurgical examination of specimens were only observed in one foundry¹.

- (vii) The charging is carried out manually and different raw materials are not weighed before being fed into the furnace. The operation of the cupola depends entirely on the experience and judgement of the operator. All these factors indirectly lead to higher coke consumption in the furnaces.
- (viii) Instrumentation is totally absent and even important parameters like melt temperature are not monitored.

Only two foundries observed were aware of the need for, and using, shop floor techniques for the control of metal quality. Proper temperature measurements, thermal analysis for the determination of carbon/silicon contents and wedge tests for the assessment of chilling tendency are important controls if engineer quality castings are to be produced¹.

Even a simply constructed manometer to indicate variations in blast pressure will enable cupola operating conditions to be monitored and action to be improve melting performance¹.

It should be noted that none of the DBCs in the cluster were fitted with automatic blast control system which would improve the performance further¹.

- (ix) For the conventional cupolas (which constitutes around 90% of the furnace population in the cluster), the best option identified is to retrofit these furnaces to divided blast operation. The cost of retrofitting, which is expected to be around Rs 50000, will be paid back in less than 2 months.
- (x) The hot blast cupola operating in the cluster had the lowest reported coke consumption. It may be worthwhile considering heat recovery methods using simple recuperative equipment i.e. without combustion of the flue gases¹.

- (xi) Some other technology options like oxygen enrichment would help in improving the energy efficiency. However, such measures are capital intensive and since the units in Agra are not engaged in long daily melting campaigns, the applicability of these technology options need a more in-depth analysis.

The scope for improving energy efficiency in the industry is great subject to the cooperation of the foundry owners and their Associations.

Annexure 1

Ph: 4673,4006,4381
Grams: CASTFORGE

PROCESS AND PRODUCT DEVELOPMENT CENTRE

Ministry of Industry
A Government of India Society
Under United Nations Development Programme
FOUNDRY NAGAR, AGRA-282006 (U.P.)

PPDC/10-1/14/94 514

March 21, 1994

TEST REPORT

Source : M/s TATA Energy Research Institute
103 Jorbagh
New Delhi

Job Order No. : 110133 Dated 04.03.1994

Sample identification : Hard Coke Lump

Test specifications : Analysis for Proximate analysis &
Gross Calorific Value

RESULTS

Ash : 28.71%

Moisture : 0.56%

Volatile : 3.41%

Matter

G.C.V : 5136.98 Kcal/Kg

TESTED & CERTIFIED BY

APPROVED BY

RBS-fv/22.3.94

(R.B. SINGH)
ASSTT. DIRECTOR (TESTING)

(R. B. SINGH)
Asstt. Director (Iron Testing)

This report pertains only to the sample submitted for the test.

(A Government of India Society)
Foundry Nagar, Agra-282006

Arvind Kumar

(ARVIND KUMAR)
JT. DIRECTOR (TESTING)
(ARVIND KUMAR)

A National Centre For Small Scale Casting & Forging Industries



Annexure 1

Ph: 4673,4006,4381
Grams: CASTFORGE

PROCESS AND PRODUCT DEVELOPMENT CENTRE

Ministry of Industry
A Government of India Society
Under United Nations Development Programme
FOUNDRY NAGAR, AGRA-282006 (U.P.)

PPDC/10-1/14/94/213

March 17, 1994

TEST REPORT

Source : M/s Tata Energy Research Instt.
103 Jorbagh
New Delhi

Job Order No. : 110132 Dated 04.03.1994

Sample identification : Cast Iron Scrap

Test specifications : Chemical Analysis for :
C, Si & Mn.

RESULTS

Carbon (C) : 3.90%
Silicon (Si) : 1.12%
Manganese (Mn) : 0.62%

TESTED & CERTIFIED BY

APPROVED BY

RBS-*fr* / 17.3.94

(R.B. SINGH)
ASSTT. DIRECTOR (TESTING)

Asstt. Director (Testing)

Arvind Kumar / 17.3.94

(ARVIND KUMAR)
JT. DIRECTOR (TESTING)

(Joint Director (T))

This report pertains only to the sample submitted for the test.

Annexure 1

Ph: 4673,4006,4381
Grams: CASTFORGE

3/5

PROCESS AND PRODUCT DEVELOPMENT CENTRE

Ministry of Industry
A Government of India Society
Under United Nations Development Programme
FOUNDRY NAGAR, AGRA-282006 (U.P.)

PPDC/10-1/14/94/212

March 17, 1994

TEST REPORT

Source : M/s Tata Energy Research Instt.
103 Jorbagh
New Delhi

Job Order No. : 110131 Dated 04.03.1994

Sample identification : Cast Iron Component

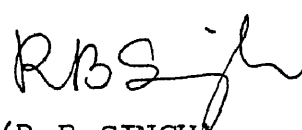
Test specifications : Chemical Analysis for :
C, Si & Mn.

RESULTS

Carbon (C) : 3.49%
Silicon (Si) : 1.94%
Manganese (Mn) : 0.44%

TESTED & CERTIFIED BY

APPROVED BY

 17.3.94

(R.B. SINGH)
ASSTT. DIRECTOR (TESTING)

 17/3

(ARVIND KUMAR)
JT. DIRECTOR (TESTING)
(ARVIND KUMAR)

This report pertains only to the sample submitted for the test.

(A Government of India Society)

Foundry Nagar, Agra-282006

Annexure 1

SHRIRAM INSTITUTE FOR INDUSTRIAL RESEARCH

(A UNIT OF SHRIRAM SCIENTIFIC & INDUSTRIAL RESEARCH FOUNDATION, DELHI)
19, UNIVERSITY ROAD, DELHI-110007.

Telegram : 'SRISANDHAN'

Telephone: 7257267

Telex : 031-78051

Fax : 91-11-7257676

Issued to :

M/s Tata Energy Research Institute (TERI),
103-Jor Bagh,
New Delhi-3

TEST CERTIFICATE



No. 140612 - 403-020-0236

Date: 22.3.94

KIND ATTN. :- Mr. J. Mishra

Your Ref. No.: ---

Sample Particulars:

Date: ---

One sample described as Lime Stone, was received.

TEST RESULTS

(As received basis)

<u>S.No.</u>	<u>Test Carried Out</u>	<u>Test Value</u>
1.	Calcium Carbonates, (as CaCO_3) % by mass	96.43

AUTHORISED SIGNATORY

- NOTE
- 1 The result listed refer only to the tested samples and applicable parameters. Endorsement of products is neither inferred nor implied.
 - 2 Total liability of our Institute is limited to the invoiced amount.
 - 3 Samples will be destroyed after one month from the date of issue of test certificate unless otherwise specified.
 - 4 This report is not to be reproduced wholly or in part and cannot be used as an evidence in the Court of Law and should not be used in any advertising media without our special permission in writing.

SHRIRAM INSTITUTE FOR INDUSTRIAL RESEARCH(A UNIT OF SHRIRAM SCIENTIFIC & INDUSTRIAL RESEARCH FOUNDATION, DELHI)
19, UNIVERSITY ROAD, DELHI-110007.

Telegram : 'SRISANDHAN'

Telephone: 7257267

Telex : 031-78051

Fax : 91-11-7257876

Issued to :

TEST CERTIFICATEM/s Tata Energy Research Institute (TERI),
103-Jor Bagh,
New Delhi-3No. **140613** 403-020-0237

Date: 22.3.94

ng

KIND ATTN:- Mr. J. Mishra

Your Ref. No.: ---

Sample Particulars:

Date: ---

One sample described as Slag, was received.

TEST RESULTS

(As received basis)

<u>S.No.</u>	<u>Test Carried Out</u>	<u>Test Value</u>
1.	Lime (as CaO), % by mass	25.5
2.	Ferrous Oxide (as FeO), % by mass	2.84

AUTHORISED SIGNATORY

- NOTE
1. The result listed refer only to the tested samples and applicable parameters. Endorsement of products is neither inferred nor implied
 2. Total liability of our Institute is limited to the invoiced amount.
 3. Samples will be destroyed after one month from the date of issue of test certificate unless otherwise specified.
 4. This report is not to be reproduced wholly or in part and cannot be used as an evidence in the Court of Law and should not be used in any advertising media without our special permission in writing

Power consumption of cupola blower/fan

The major electrical load in cupola operation is the energy requirement for blowers/fans. The capacity of the blower must be such as to supply air at the correct volume for combustion and pressure so that the air penetrates the coke bed and high core temperatures are developed. The recommended blowing rate for a conventional cupola is 115 m³/min-m² of melting zone cross sectional area (375 ft³/min/ft²). Blast rates of below 20% or above 20% of this figure would result in unsatisfactory cupola operation. Blowing pressure will depend on the size of cupola. The requirements of blower volume and pressure for 48" and 42" diameter cupolas are given below.

48" dia cupola	-	Volume	: 160 m ³ /min (5660 ft ³ /min)
		Pressure	: 12.7 kPa (51 inch w.g.)
42" dia cupola	-	Volume	: 123 m ³ /min (4350 ft ³ /min)
		Pressure	: 12 kPa (48 inch w.g.)

The recommended blower/fan volume capacity is based on the recommended blowing rate plus 20%. The discharge pressure is approximately 50% higher than the anticipated windbelt pressure.

The blast rate and pressure recommendations are the same for both conventional and divided blast cupolas. In divided blast operation it is generally recommended that the blast is equally divided between the upper and lower row of tuyeres. Separate windbelts are provided and the air supply must be proportioned accurately using automatic air supply control system. Because of the variations in the internal resistance in the cupola, divided blast operation cannot be achieved by the use of manually adjusted valves of dual fan systems.

In most cases the blast air for conventional cupolas is supplied using centrifugal fans. Positive displacement blowers are sometimes used but these are mainly confined to larger cupola installations and particularly larger recuperative hot blast systems which operate for longer periods under optimum conditions. Whilst the pumping efficiency of a positive displacement blower (Roots type) is good, the mechanical efficiency is lower and

part-load operation is uneconomical. A centrifugal high efficiency, shrouded impeller type fan is preferable. The starting loads with centrifugal fans are also lower.

The inefficiency in cupola operation results from poor maintenance and damaged blower systems. Worn, damaged or dirty fans become rapidly inefficient. Leaky fan casings, duct joints, valve pivots and tuyere covers result in loss of both blast pressure and volume. It is also important that the tuyere openings are correctly sized.

Whilst the correction for lagging power factors resulting from inductive loads using capacitors at the individual machine or main busbar may result in small savings, the diversification of load on the factory supply which may also sustain reactive loads is important in estimating the billed electricity consumption. The savings to be gained by correction (properly installed to ensure that safety is not degraded) may be small but could justify the cost.

Annexure 3

Factors affecting efficient operation of cold blast cupolas

Many operational variables exist which can affect the efficiency of a cold blast cupola and its ability to produce molten iron of the correct composition and temperature for the pouring of defect free castings having the desired mechanical properties. Close control of the cupola operation is necessary for most economical and efficient operation. The following are some most important aspects of cupola operating practices:

(1) *Charge composition must be calculated based on required final chemical composition*

For low grade castings it is possible to produce iron to specification (carbon and silicon content) using carbon equivalent values (CEV) obtained by simple thermal analysis techniques. It is also necessary to consider the influence of other elements such as sulphur, phosphorus and manganese which are present in the iron and also the influence of impurities such as aluminium and lead which can cause inferior mechanical strength. For higher grades of grey cast iron and for the production of ductile base iron very careful control of metal composition requiring analytical laboratory facilities are needed.

(2) *Charging materials should be carefully selected based on grade and quality of iron required*

Metallic charge generally comprise a combination of scrap cast iron pieces, steel scrap and suitable grades of pig iron together with additives such as ferro-silicon and ferro-manganese. It is necessary to calculate a charge based on known or estimated composition of the charge materials, taking into account the chemical changes within the cupola during melting, e.g. carbon gain, silicon loss, manganese loss and sulphur pickup.

(3) *Charge materials must be sized correctly*

Very large scrap pieces would result in open charge allowing too easy a passage of gases through the charge in the cupola shaft thus preventing proper preheating of the charge prior to melting zone. These large pieces may bridge in the cupola shaft preventing charge materials descending into the melting zone. The result would be low melting rates and variable tapping temperature.

Conversely charge materials should not be too small as these restrict the flow of

gases in the shaft and increase internal pressure in the cupola thus restricting the blast rate. Again the result is variable melting rate and tapping temperatures.

(4) *Coke should be correctly graded (sized) and have low ash and sulphur contents.*
Strong coke is necessary to avoid degradation during handling and prior to combustion in the cupola.

(5) *All metal and coke charges must be weighed*
The bulk density of both scrap iron and steel pieces and of coke varies considerably depending on piece configuration and size. Charge quantities estimated either "by eye" or volumetrically would lead to errors in charge weight. Upto $\pm 25\%$ error in readings are likely to result from these practices.

(6) *Charge materials should not be excessively contaminated*
Low grades of machinery and municipal scrap will contain a high level of impurities and rubbish, much of which will be combustible. It is not unusual to find a melting loss of 5-10% in foundries using low grade materials due to non-metallic contamination.

(7) *Optimisation of cupola operation*
Higher coke charges or use of additional facilities such as oxygen enrichment will be necessary if a cupola is operated where the demand for molten metal is not constant and no metal holding facilities are available.

(8) *Cupolas must be operated for the longest practicable melting campaign*
The length of campaign of a conventional cupola is limited by the burnback of the lining materials in the melting zone. Using siliceous lining material (which are necessary for correct slag chemistry to be maintained) of reasonable quality, operating times of upto 10 hours are practicable. The operating period should not, however, be extended at the expense of optimum running conditions, as this is likely to be counter-productive in energy use. Especially with divided blast cupolas (DBC's), the length of the melting campaign is important as the additional bed coke used must be amortized against charge coke savings arising from this method.

(9) *Proper maintenance of blowers, blast mains, windbelts and tuyere elbows*
Many cupolas do not operate efficiently because the designed blast volumes and pressures are not achieved. This is due to poor maintenance of fans and leaks in the systems.

Furthermore tuyeres should be properly sized and of correct numbers to suit the diameter and melting rate of the cupola. The ductwork should not have complex bends or restrictions which otherwise would cause pressure losses. These remarks apply whether or not conventional or divided blast systems are used although in the latter case effects can be more serious due to the inability to maintain the correct balance between the upper and lower rows of tuyeres.

(10) *Maintain good yield*

The true yield (good castings/metal charged) of good castings (saleable product) from the metal charged is rarely known by foundries with any degree of accuracy. Improvement in yield, however, results in significant cost savings.

Improvements in the casting/poured weight ratio, reduced metal spillage and pigged metal for remelting, together with improved scrap performance can be achieved from better control of tapping temperatures, composition and metal cleanliness arising from better furnace operation. These would improve the overall yield.

The overall energy consumption per tonne of castings produced is a more important parameter than direct melting energy consumption and this depends on the yield. The melting energy cost per tonne of metal melted must therefore be adjusted by the known, or predicted yield of good castings from metal charged to give a true estimate of overall energy cost and usage.

Annexure 4

Emission control and gas cleaning for cold blast cupolas

Cupolas are charged with a wide range of ferrous materials, many of which contain loose particles of oxide and non-metallic materials, or have particles adhering to them. Additionally, particles may be accidentally picked up from stock storage areas. The handling, weighing and delivery of charge materials into the furnace causes further abrasive degradation and the consequent generation of particulate material. In cupola, when the charge materials rub against each other, the refractory lining generate more particles.

Coke burnt in cupolas produce CO_2 , CO and SO_2 , leaving a residue of ash, some of which will enter the rising gases in the cupola. Solid particles from all sources are contained in the gases rising through the cupola charge material and if they are light enough they will be carried out of the cupola in the exhaust gases. The small particle size of metallurgical fume makes it visible on discharge and is mainly responsible for the characteristic plume from the cupola stacks. The metallurgical fume emissions from cold blast cupolas increase with:

- increasing proportions of coke in charge
- increasing proportions of steel in charge
- increasing the injection rate of oxygen into the cupola blast air or directly into the tuyeres or well
- The level of contamination of scrap steel with non-ferrous metals e.g. zinc and lead.

The range of metallurgical fume emission rate from normal coke fired cupolas is generally between 0.5-2.0 kg/tonne of melt. The fume is generally composed of particles less than 1 μm in size or possible agglomerates of these particles as distinct from the dust emission where particle size can range above 1 μm .

Dust originates from particles broken off charge materials, lining abrasion and non-metallic debris. The higher the blowing rate of the cupola the higher will be the dust content of the top gases due to high gas velocities in the cupola.

Another principal component of cupola emissions is carbonaceous smoke caused by the incomplete combustion of organic matter. These emissions arise from the contamination of scrap with paint/oil or substances such as rubber and textiles. The hot, oxygen free atmosphere in the cupola shaft generates smoke from all these sources.

It is possible to capture dust in relatively simple collectors and carbonaceous smoke can be controlled using afterburners in the cupola stack. The cleansing of cupola exhaust gases to remove metallurgical fume presents more difficulties and only highly efficient filtration or scrubbing systems can adequately clean the top gas to the levels of invisibility, i.e. solids content of less than about 100mg/m^3 . Several methods on high efficiency gas cleaning have been applied to cold blast cupolas and these are described below:

1. Fabric filters

Fabric filters consume less power than equivalent high efficiency wet scrubbing systems. However, cupola gases must be burnt before entering fabric filters; otherwise the filter material eventually becomes uncleanable and to combust CO. The gases must also be cooled, prior to filtration, by water quenching or other means. However, a fabric filter cannot be used directly below charge off-takes and would need to be used later in the system where the gas flow would be higher. The capital cost of fabric filters is generally higher than for wet scrubbers.

2. Electrostatic precipitators (ESPs)

ESPs have not proven to be popular for cleaning cupola exhaust gases. The top gases need to be burned prior to cleaning. ESPs work best with constant gas conditions which are not normally achievable with cold blast cupolas. The principal benefit of ESPs is the much lower power consumption than high intensity scrubbers. However, the capital and maintenance costs are high.

3. High intensity scrubbers

High intensity scrubbers are widely used devices for fume cleaning on cold blast cupolas and will effectively reduce emissions to about 100 mg/m^3 . Most scrubbers are based on the use of a high energy venturi. The only visible emission arising from the plant is a water vapour plume from the stack. The solid material is removed from the plant in the circulated water and pumped to settling tanks for separation as sludge. To aid disposal of the sludge it is advisable on any large installation to include a filter press so that the solids can be dewatered for easy removal. The cupola gases may contain SO_2 and other gases which dissolve in water to form acidic compounds, therefore, it is necessary to protect wet

scrubbing system from corrosion, either by neutralisation of the plant water and/or the construction of the equipment with stainless steel and other corrosion resistant materials.

The power consumption of high energy venturi scrubbing systems is fairly large. Table I gives a comparison of various collection methods. Also to ensure that exhaust gases and particulate matter are prevented from escaping from the cupola charge opening, it is necessary to maintain an intake air velocity in excess of 1 m/sec. The size of the charge opening is therefore important as with large areas of the capacity of the gas cleaning system. When designing new cupolas the charge opening is therefore kept as small as possible and vibrating feeders or similar devices can be used.

Table I. Comparison of collection methods

Method	Ability to give invisible emission	Typical weight of dust	Cost index	Power index	Water pollution	Comment
Simple wet collector	No	4	1	1	Yes	Simple, cheap. Remove 50-60% dust.
Multicyclones	No	2	5	10	No	Simplest of powered collectors. Meets some regulations.
Medium/low intensity scrubber	No	0.4 - 2	5	12	Yes	Some designs can be upgraded to high efficiency.
High intensity scrubber	Yes	0.4 or less	8	49	Yes	Simplest collector capable of cleaning gases to invisibility. Cheapest of high efficiency units but uses most power
Wet electrostatic precipitator	Yes	0.4 or less	15	10	Yes	Complex. Sensitive to gas conditions. Potential explosion hazard.
Dry electrostatic precipitator	Yes	0.4 or less	15	10	No	Complex. Sensitive to gas conditions. Potential explosion hazard.
Fabric filter	Yes	0.02	12	15	No	Needs good maintenance. Collected dust may need treatment to prevent dust nuisance.

Benefits of divided blast operation of cupolas

The history of the divided blast cupola (DBC) dates back to 1972 when work done by Leyshon and Selby at BCIRA showed that cupola performance could be improved if the blast was divided between two rows of tuyeres. The original work was carried out on an intermittently tapped cupola in the BCIRA experimental foundry and subsequently the divided blast principle was widely adopted in the UK and worldwide.

Further work was carried out at BCIRA during 1983 by Coon, Blackman and Wickins when it was noted that tapping temperatures at given coke charges in both conventional and DBCs had substantially increased. However, this was more noticeable in conventional cupolas (tapping temperature increases of up to 50 °C) than in DBCs where only about 20 °C increases were observed. The difference was greatest in DBCs tapped on a continuous basis. The differences were attributed to undefined changes in the quality of coke from UK and European sources which could not be detected by the regular tests. These observations led to further work which established the importance of the well depth of cupolas operated continuously. It has now been shown that in addition to the tuyere spacing and distribution of air between the two rows of tuyeres well depth is an important factor in determining the performance of the continuously tapped DBC.

Optimum conditions were a spacing of approximately 900 mm with equal division of the blast between the two rows. The use of divided blast permitted (i) increase in metal tapping temperature by 45-50 °C and (ii) increase in carbon content by up to 0.15% in comparison with conventional cupola.

Divided blast operation could be used at the same coke charge to increase metal temperature and carbon pick-up. Alternatively, if the same tapping temperature were to be maintained, the coke charge could be reduced or the melting rate increased. At a constant coke charge a proportion of the pig iron in the charge could be replaced by steel scrap and if tapping temperature were maintained at the same level as much as 25% reduction in coke charges could be sustained. To obtain the highest metal temperatures and thermal efficiency, an additional design requirement is therefore to position the lower row of tuyeres as close as is practicable above the tap hole.

Divided blast operation can only be fully effective when a well engineered plant is operated under optimum conditions. It is not generally recommended for very small cupolas (less than 3 tph) or those used for very short operating periods. Coke consumption in small DBC or the furnace used for a few hours per day may not be better than in a conventional cupola. This is because of the additional bed coke requirement. A starting height for the coke bed must be at least one metre above the top row of tuyeres. This additional coke will be lost during blowdown/cupola drop and will not be consumed as fuel for melting. The appropriate bed/charge coke quantities must be estimated and compared with the benefits of divided blast operation a decision on cupola configuration is made.

Volume 3

**Energy audit
in
Firozabad glass industry cluster**

Contents

Chapter 1

Introduction 1 - 3

Chapter 2

Energy audit: Oil fired tank furnace 4 - 24

Chapter 3

Energy audit: Coal fired tank furnace 25 - 40

Chapter 4

Energy audit: Closed pot furnace 41 - 49

Chapter 5

Energy audit: Open pot furnace 50 - 57

Chapter 6

Energy audit: Muffle furnace (Pakai Bhatti) 58 - 65

Chapter 7

Conclusions 66 - 71

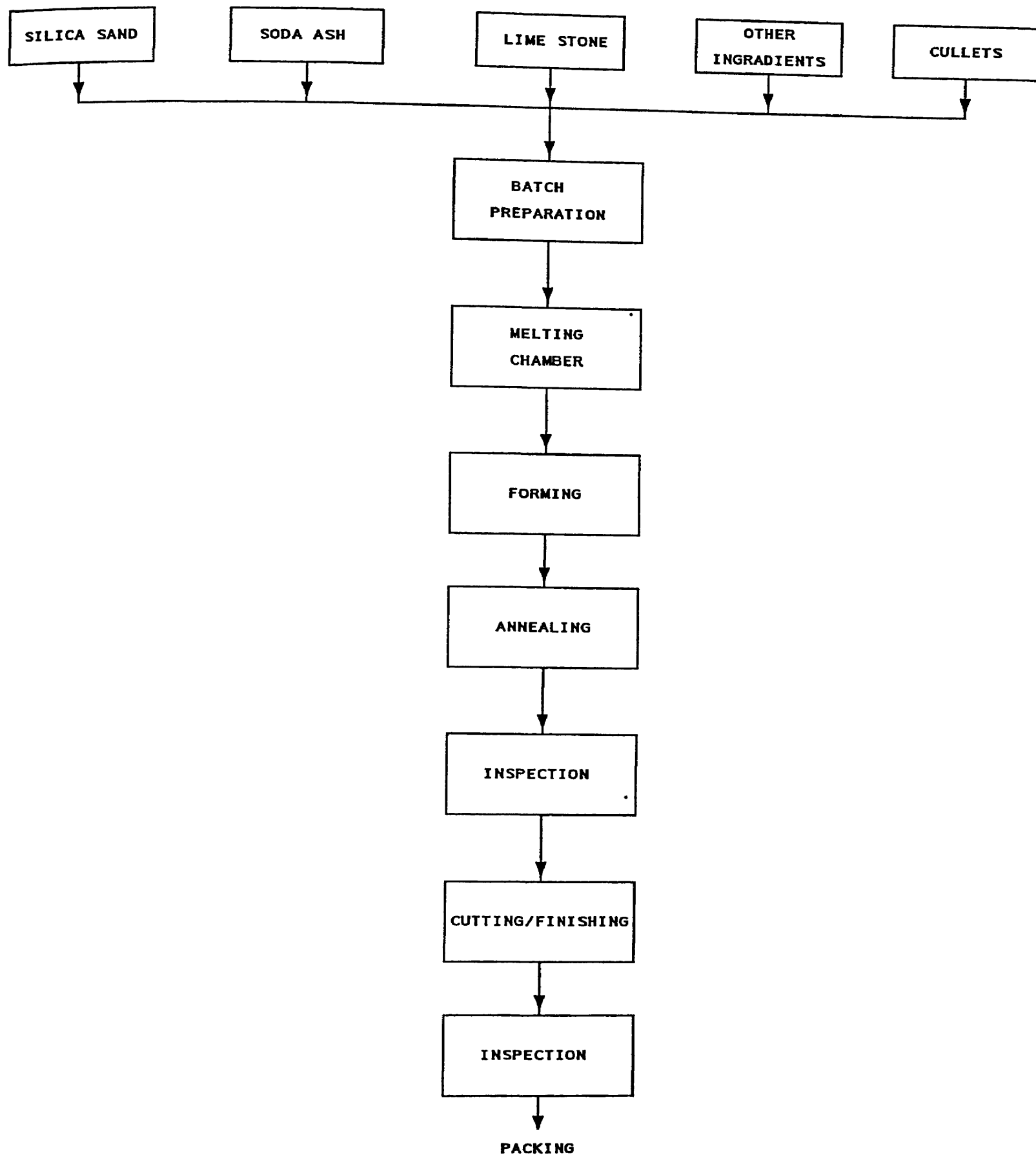


**FIG 1.1 PROCESS FLOW DIAGRAM IN
GLASS MANUFACTURING**

Introduction

The glass industry at Firozabad was identified as one of the clusters to be studied in detail under the energy sector study. Firozabad is a small town in the state of Uttar Pradesh situated 40 km from Agra. The cluster of glass units at Firozabad occupies a special position as the industry accounts for 70% of the total glass production in the small scale sector. There is a large agglomeration of small scale units engaged in the manufacture of hollow-ware, decorative items, glass beads, bulbs, headlight covers and bangles. The process flow steps in a glass melting unit is shown in figure 1.1. The different types of glass melting furnaces employed in the cluster are shown in table 1.1 along with number of units in operation and the typical capacity ranges. In addition, there are four automatic oil-fired furnaces in the cluster.

Table 1.1. Types of furnaces employed at Firozabad cluster

Furnace type	Number of registered units	Units operating	Capacity (tpd)
Tank furnace (coal-fired)	30	15	15-25
Tank furnace (oil-fired)	6	6	15-25
Open pot furnace	200	50	5
Closed pot furnace	40	30	4
Muffle furnace	400	400	-

The major forms of energy used in the cluster are coal and R.F.O. The total consumption of coal is estimated to be 730 tpd and of R.F.O. is 25 kL per day in the entire Firozabad cluster. The glass industry in Firozabad suffers from gross inefficiency primarily because of the outmoded design of the furnaces and gasifiers. The industry is highly energy intensive with the fuel cost accounting for 40% of the total product cost. Along with the problem of energy inefficiency, the units also have to cope up with low productivity with the capacity utilisation being reported as 45%, which significantly affect their competitiveness and urge to upgrade their technology level.

Being located inside the Taj Trapezium, the units are also faced with the challenge of reducing stack emissions to comply with the emission standards stipulated by Uttar Pradesh Pollution Control Board (UPPCB).

The present study was undertaken with a view to identify measures to improve the energy efficiency of the Firozabad glass industry cluster. In order to identify the energy conservation opportunities, energy audit was carried out in one unit each under different furnace types as listed in table 1.1. As there are lot of similarities between similar furnace types with regard to technology level, operating practices, etc., the outcome of the energy audits could be broadly applied to other similar units in the cluster. In addition to energy audit, some broad-based strategies were also identified which would lead to an overall improvement in energy efficiency and a proportional reduction in the pollution load.

This report contains the results of the energy audits carried out in five units, employing (i) oil-fired tank furnace, (ii) coal-fired tank furnace, (iii) closed pot furnace, (iv) open pot furnace and (v) muffle furnace. The unit specific energy audit reports are being followed by the overall assessment outlining energy conservation measures, which can be implemented at the plant level and to the cluster as a whole, including some long-term measures.

Energy audit : Oil fired tank furnace

2.1 Introduction

The unit manufactures a wide range of glass products such as bulb shells, head light covers, tumblers, bangles and other glassware items. It employs an oil-fired, regenerative, tank furnace with a melting capacity of 25 tpd, operating on a continuous basis. A plant visit was undertaken in order to study the details of the process employed and to carry out energy audit of major energy consuming centres such as the glass melting furnace and the annealing Lehr. Detailed energy balance of the furnace and the annealing Lehr were carried out with a view to evaluate the thermal efficiency of the furnace and the Lehr and to identify areas where there is a scope for minimising energy wastage. The measurements taken, observations made and the results of the analysis are outlined in the following sections.

2.2 Process description

The manufacturing process of glass products can be divided into six steps namely, (i) batch charge preparation, (ii) glass melting, (iii) drawing & blowing of the melt to required shapes, (iv) annealing, (v) cutting and (vi) sorting & packaging. Out of these, the two process operations, namely, melting and annealing are the most energy intensive, accounting for more than 95% of the total energy consumption in the unit. A schematic diagram of the oil fired tank furnace is shown in **figure 2.1**. Some selected details of the furnace are shown in **table 2.1**.

Table 2.1. Details of oil fired tank furnace

Furnace type	End port, regenerative, tank furnace
Melting capacity	25 tpd
Fuel used	Residual fuel oil (R.F.O)
Fuel consumption	5.2 kL/day

2.3 Glass melting furnace

The batch charge fed to the furnace primarily consists of silica sand, soda ash, calcium carbonate and cullets. Culletts are glass rejects from various operations in the manufacture

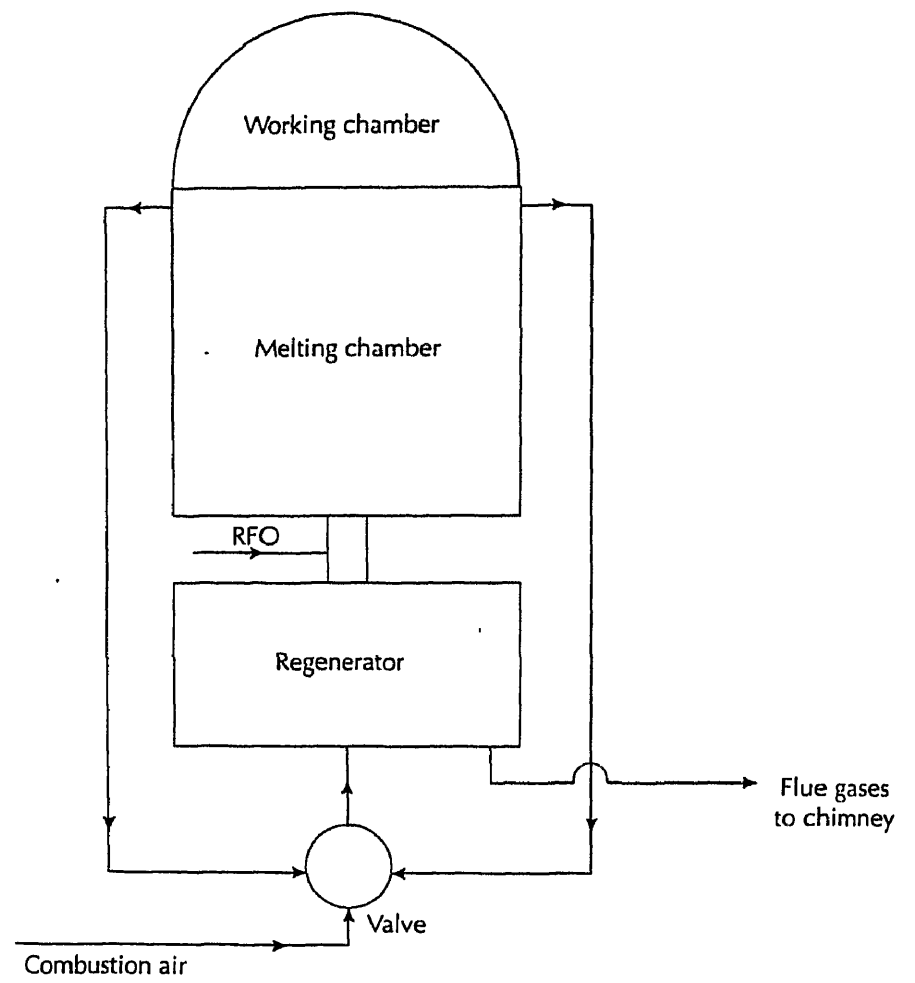


Fig. 2.1 Oil fired tank furnace

of glass products. The major constituent, silica sand contains about 96% of silica (SiO_2) by weight. A chemical analysis of silica sand used in the unit is shown in table 2.2.

Table 2.2. Chemical analysis of silica sand

Constituent	Percentage (by weight)
SiO_2	96.48
Al_2O_3	1.09
Fe_2O_3	0.03
CaO	0.90
MgO	1.50

Silica is the principal glass forming oxide and thus an important constituent in the process. Limestone is used as a source of calcium oxide to impart durability to glass. Soda ash (Na_2CO_3) is the primary fluxing agent in the batch. Fluxing (or lowering) of the melting point which gives improved workability to the glass is accomplished by Na_2O in soda ash. Prior to feeding into the furnace, the raw materials are weighed and blended with other minor batch ingredients as per requirement. The batch charge is then fed to the tank furnace.

The tank furnace is an oil fired, end port, regenerative type with a glass melting capacity of 25 tpd. The refractory used in the furnace is silliminite bricks. The life of insulation was reported to be one year. There are fourteen gathering holes each of 9 x 9 inch size to draw the glass melt from the working chamber. The temperature of the glass melt is maintained at around 1470 °C. The combustion air is preheated to about 950 °C in the regenerator. The checker structure inside the regenerator is made up of a lattice of refractory bricks.

The hot flue gases and the combustion air pass through two separate chambers in the regenerator. A flow reversing valve, which is operated manually, is provided at the regenerator air inlet position, for reversing the flow of combustion air and flue gases after every 20 minutes. The sensible heat in hot flue gases is extracted by the refractory bricks during the passage of flue gases, and is utilised to preheat the incoming combustion air when the flow of air and flue gases are reversed. The preheating of combustion air helps in providing higher flame temperature and melting efficiency due to recovery of waste heat from flue gases. The flue gases leave the regenerator at about 400 °C to the stack without further heat recovery.

The overall rejection rate of glass at the unit is about 67% of the total melt drawn. The rejection of the product takes place at different stages of product making. A major portion of rejection takes place during the cutting operation followed by rejections during annealing, sorting, packaging and also due to mal-handling of the products.

2.3.1 Fuel

The fuel used in the melting furnace is R.F.O. The furnace consumes about 5.2 kL of R.F.O per day corresponding to a glass melt of 25 tpd. A sample of R.F.O. was collected during energy audit and was analysed for its chemical constituents, the results of which are given in **annexure 2.1**. The fuel characteristics are also shown in **table 2.3**. As can be seen from the table, R.F.O has a sulphur content of 3.1% and gross calorific value of 10,450 kcal/kg.

Table 2.3. Characteristics of R.F.O.

Component	Percentage (by weight)
Carbon	83.0
Hydrogen	11.3
Sulphur	3.1
Oxygen	0.5
Ash	0.1
Moisture	2.0
Gross calorific value (kcal/kg)	10,450

2.4 Heat balance of the melting furnace

A detailed heat balance of the melting furnace was carried out for evaluating the melting efficiency of the glass furnace and to quantify major energy losses. *The melting efficiency of the furnace is defined as the ratio of the heat in the glass melt to the heat supplied by the fuel.* The following heat components were computed for carrying out the heat balance of the glass melting furnace.

- (1) Flue gas loss
- (2) Heat in glass melt
- (3) Structural losses

The various operating parameters measured and the detailed computation of different heat components are enclosed in **annexure 2.2**. The summary of the heat balance for the glass

melting furnace is given in **table 2.4**. A sankey diagram showing various heat components associated with the furnace is given in **figure 2.2**.

Table 2.4. Heat balance of oil fired tank furnace

Heat component	Percentage
Heat in glass melt	21.3
Flue gas loss	21.8
Structural losses	56.9

The efficiency of the furnace for glass melting is 21.3% of the total fuel heat input. The analysis of heat balance indicates that the major areas of heat loss are (i) flue gas loss (21.8%) and (ii) structural losses (56.9%). Flue gas loss includes loss due to hydrogen & moisture in fuel and moisture in air besides the loss due to sensible heat in dry flue gases. The structural losses was computed as the difference of heat input and sum of all the heat components. The fuel to melt ratio was computed to be 0.2 kg/kg. The specific energy consumption was 2.1 Gcal/tonne of melt.

2.5 Regenerative air preheater

The melting furnace is provided with a regenerative air preheater for preheating the combustion air to about 952 °C by utilising the waste heat in flue gases. About 39.1% of the fuel heat input to the furnace is recovered in the regenerator. The flue gases enters the chimney after the regenerator at 400 °C. The details of the computation of the heat gain by the combustion air in the regenerator are given below.

Quantity of air handled	=	3016 kg/hr
Inlet air temperature to regenerator	=	37 °C
Outlet air temperature from regenerator	=	952 °C
Specific heat of air	=	8.92 kcal/kmol°K
Heat gain by combustion air	=	850366 kcal/hr
Heat input to the furnace	=	2173600 kcal/hr
Percentage heat gain by combustion air	=	39.1%

2.6 Recommendations

The melting of glass is the most energy intensive operation in a glass unit which accounts for more than 90% of the total energy consumption of the unit. Hence, significant improvement in energy efficiency is possible in the melting furnace. Based on the analysis of the energy audit data, a set of measures are suggested below, to improve the energy

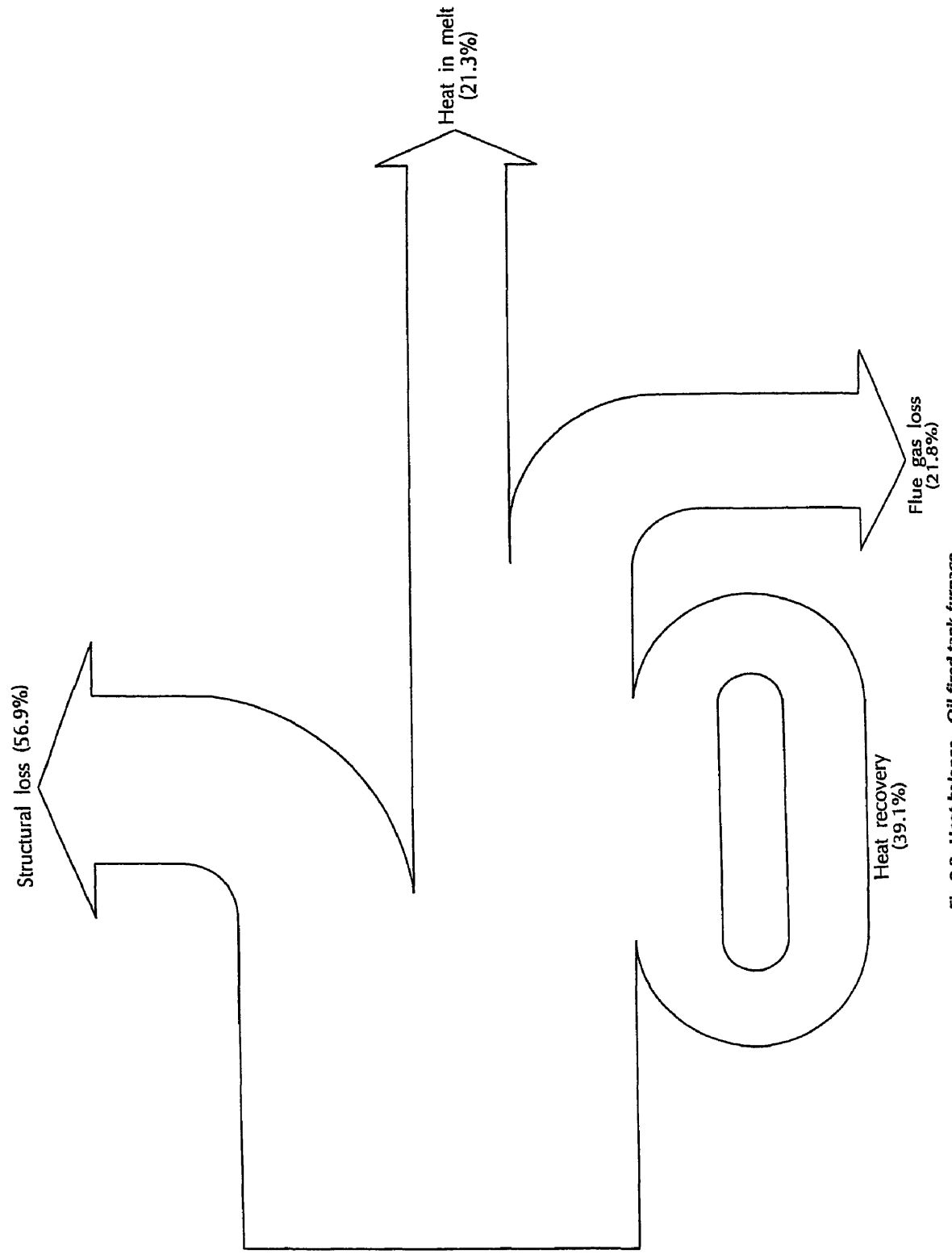


Fig 2.2 Heat balance - Oil fired tank furnace

efficiency of the furnace. For some of the suggested measures, cost/benefit analysis could not be provided as such systems are not common in the Indian glass industry. These options are, however, widely applied in the developed countries and specific techno-economic feasibility studies can be taken up with focus on applying these newer technology options in Indian glass industry.

2.6.1 Reduction of excess air level

The oxygen and CO content in the flue gas were used to compute the excess air level. The parameters measured for computing the flue gas heat loss are oxygen content in flue gas and exit flue gas temperature. The flue gas heat loss was computed to be 21.8%. The actual air flow was also measured with an anemometer, the results of which are summarised in **annexure 2.3**. The furnace is operating at an excess air level of 19%. This can be brought down to 10% without effecting the combustion efficiency of the furnace. The achievable energy savings by optimising the excess air will be about 1% of the fuel input. This amounts to an annual saving of around 15.6 kL of R.F.O. equivalent to a monetary saving of Rs 80,000 per year, under the existing operating conditions.

In order to effectively control the excess air, monitoring of oxygen content in the flue gas is essential. The plant must use flue gas analyser to measure the oxygen content in flue gases and control the excess air to the optimum level. The cost of a simple oxygen monitor is about Rs 9,000 and the expenditure will be paid back in less than two months. However, as the existing burner is a simple low-pressure type, with no control mechanisms, it may not operate effectively at low excess air levels. For operating the furnace at low excess air levels, it is recommended to replace the existing burner with a low excess air/fuel-efficient burner along with fuel/air controller to respond to the varying fuel firing rates.

2.6.2 Waste heat recovery

During the audit study, it was found that the flue gases leave the regenerator at 400 °C, resulting in substantial wastage of sensible heat. Incorporation of a secondary heat recovery system in the flue gas line between reversal valve and the chimney can effectively preheat the ambient air before it is being fed to the regenerator. Since the sulphur content of R.F.O. was 3.1%, the lower limit to which the flue gas can be cooled (based on the acid dew point temperature of the flue gas) is around 160 °C. Assuming the

final exit flue gas temperature to be around 250 °C and the effectiveness of heat exchanger as 0.8, the amount of heat that can be transferred to the combustion air is 0.1 Gcal/hr.

The combustion air flow rate is 3,333 kg/hr and the possible increase in combustion air temperature with the above modification will be about 130 °C. In terms of energy saving, the above measure will lead to an annual fuel saving of 73 kL, which is equivalent to annual monetary saving of Rs 4 lakhs. The above modification, however, only be carried out when the furnace is redone during annual shutdown and the detailed techno-economic assessment of the proposed measure will have to be worked out in consultation with a glass technologist.

2.6.3 Structural losses

The structural losses was observed to be 56.9% of the total heat input. The high structural heat loss was also reflected by the high surface temperatures observed in different zones. For the order of temperature encountered in the furnace and the regenerator, the outside surface temperature should not exceed more than 50 °C over the ambient. The ambient dry bulb temperature measured during the audit was found to be 37 °C. The surface temperature measured were found to be more than 200 °C. It is possible to reduce the structural losses by at least 25% by use of better refractory bricks. The corresponding fuel saving will be around 222 kL per annum with an equivalent monetary saving of Rs 12 lakhs.

The use of ceramic fibre blankets as back-up insulating material is also gaining popularity in the glass industry. It is ideally suited for crown insulation as from the view-point of structural stability, the crown cannot be made thicker and accounts for a large share of the total heat loss. The use of low thermal mass ceramic blanket, therefore, is considered ideal for this purpose. It is to be noted, however, that better insulation should only be provided at the time of reconstruction as otherwise the thermal imbalance will lead to failure of the refractory and can lead to collapse of the structure.

2.6.4 Cullet preheating

The sensible heat in flue gases can also be utilised for preheating the cullets before being fed to the furnace. The cullets constitute about 60% of the batch charge. The flue gases can be cooled to 250 °C in the charge preheater. Preheating of the cullets to about 250 °C would result in sensible heat gain, equivalent to an annual fuel and monetary savings of

15.6 kL of R.F.O. and Rs 87,000 respectively. However, pelletising and preheating of cullets is a new concept for the Indian glass industry which needs an in-depth analysis with regard to its application in relatively smaller units.

2.6.5 Oxygen enrichment

Oxygen enrichment of the combustion air will result in reduction of flue gas loss, higher flame temperature and therefore improved radiative heat transfer, leading to improved melting efficiency. Fuel savings of 8-10% are reported elsewhere by addition of 1.6% oxygen in the combustion air. The economics of such system must be worked out in consultation with the manufacturers to see its applicability in smaller units.

Apart from the above measures, for further improvement in energy efficiency of the glass melting furnace, the following areas shall need to be examined for their techno-economic feasibility.

(a) Use of bubble system

Provision of bubble injector pipes manufactured with high grade stainless steel with recrystallised alumina at the bottom of the furnace will result in comparatively cool glass from the bottom of the tank to the surface resulting in greater heat transfer from flame to glass and improved thermal efficiency of the furnace.

(b) Glass level of container

In glass manufacture, glass level control is an integral part of the production output and any change in the level will lead to either fall in output or rejection due to excess material in glass. It is therefore essential that the glass level is maintained correctly which will result in indirect fuel savings.

2.7 Annealing lehr

Annealing lehr is used to relieve the thermal stresses and impart hardness to the glass products. The annealing lehr is an insulated channel with dimensions of 80 x 6 x 6 ft. There are two zones in the lehr, viz. the heating zone and the cooling zone, having lengths of 16 ft and 64 ft respectively. The front portion of the lehr is partly covered with a 6 x 2

ft iron plate. Glass products are fed into the heating zone on a conveyor belt which moves at a constant speed through the lehr. The products are heated to a maximum temperature of 500 °C in the heating zone, soaked at this temperature and subjected to controlled cooling in the cooling zone. It was observed during the plant visit that the flue gases do not pass through chimney; instead they are allowed to pass through entire lehr length and leaves the rear end of the lehr at about 100 °C.

2.7.1 Fuel

The fuel used in the annealing lehr is kerosene; electricity is used for running the conveyor system. The consumption of kerosene is 400 lit/day corresponding to a glass product handling of about 9 tpd. The characteristics of the fuel used is given in **table 2.5**.

Table 2.5. Characteristics of kerosene

Component	Percentage (by weight)
Carbon	85.5
Hydrogen	14.0
Sulphur	0.5
Gross calorific value (kcal/kg)	11100

2.8 Heat balance of the annealing lehr

A detailed heat balance of the annealing lehr was carried out for evaluating the operating efficiency of the lehr and to quantify major energy losses. The following heat components were computed for carrying out the heat balance.

- (1) Flue gas loss
- (2) Heat loss to conveyor system
- (3) Residual heat in glass products
- (4) Structural & cooling zone losses

The various operating parameters measured and the computation of different heat components, as outlined above, are given in **annexure 2.4**. A summary of the heat balance of the annealing lehr is furnished in **table 2.6**. A sankey diagram showing various heat components associated with the lehr is given in **figure 2.3**.

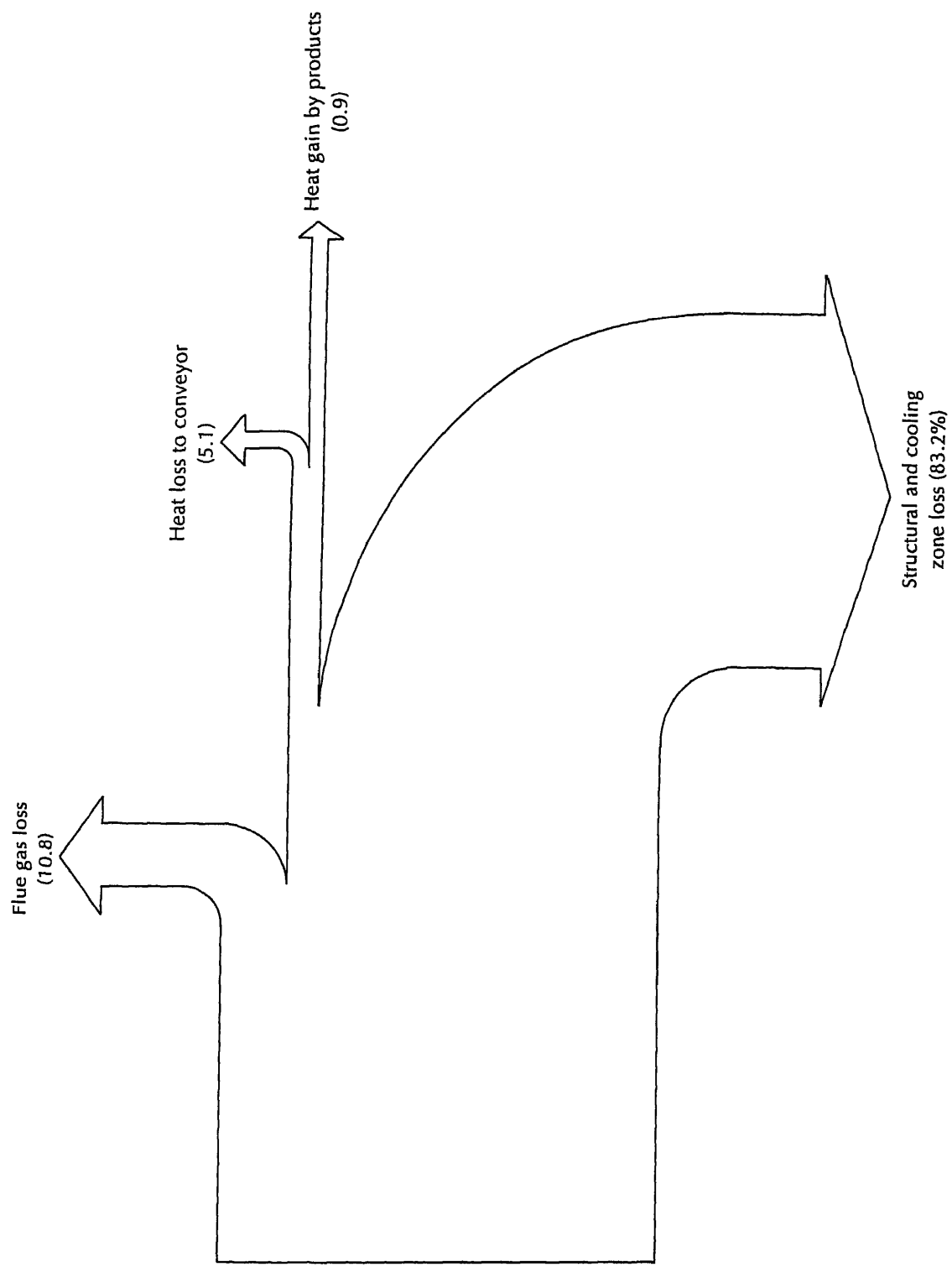


Fig 2.3 Heat balance - Annealing lehr

ft iron plate. Glass products are fed into the heating zone on a conveyor belt which moves at a constant speed through the lehr. The products are heated to a maximum temperature of 500 °C in the heating zone, soaked at this temperature and subjected to controlled cooling in the cooling zone. It was observed during the plant visit that the flue gases do not pass through chimney; instead they are allowed to pass through entire lehr length and leaves the rear end of the lehr at about 100 °C.

2.7.1 Fuel

The fuel used in the annealing lehr is kerosene; electricity is used for running the conveyor system. The consumption of kerosene is 400 lit/day corresponding to a glass product handling of about 9 tpd. The characteristics of the fuel used is given in **table 2.5**.

Table 2.5. Characteristics of kerosene

Component	Percentage (by weight)
Carbon	85.5
Hydrogen	14.0
Sulphur	0.5
Gross calorific value (kcal/kg)	11100

2.8 Heat balance of the annealing lehr

A detailed heat balance of the annealing lehr was carried out for evaluating the operating efficiency of the lehr and to quantify major energy losses. The following heat components were computed for carrying out the heat balance.

- (1) Flue gas loss
- (2) Heat loss to conveyor system
- (3) Residual heat in glass products
- (4) Structural & cooling zone losses

The various operating parameters measured and the computation of different heat components, as outlined above, are given in **annexure 2.4**. A summary of the heat balance of the annealing lehr is furnished in **table 2.6**. A sankey diagram showing various heat components associated with the lehr is given in **figure 2.3**.

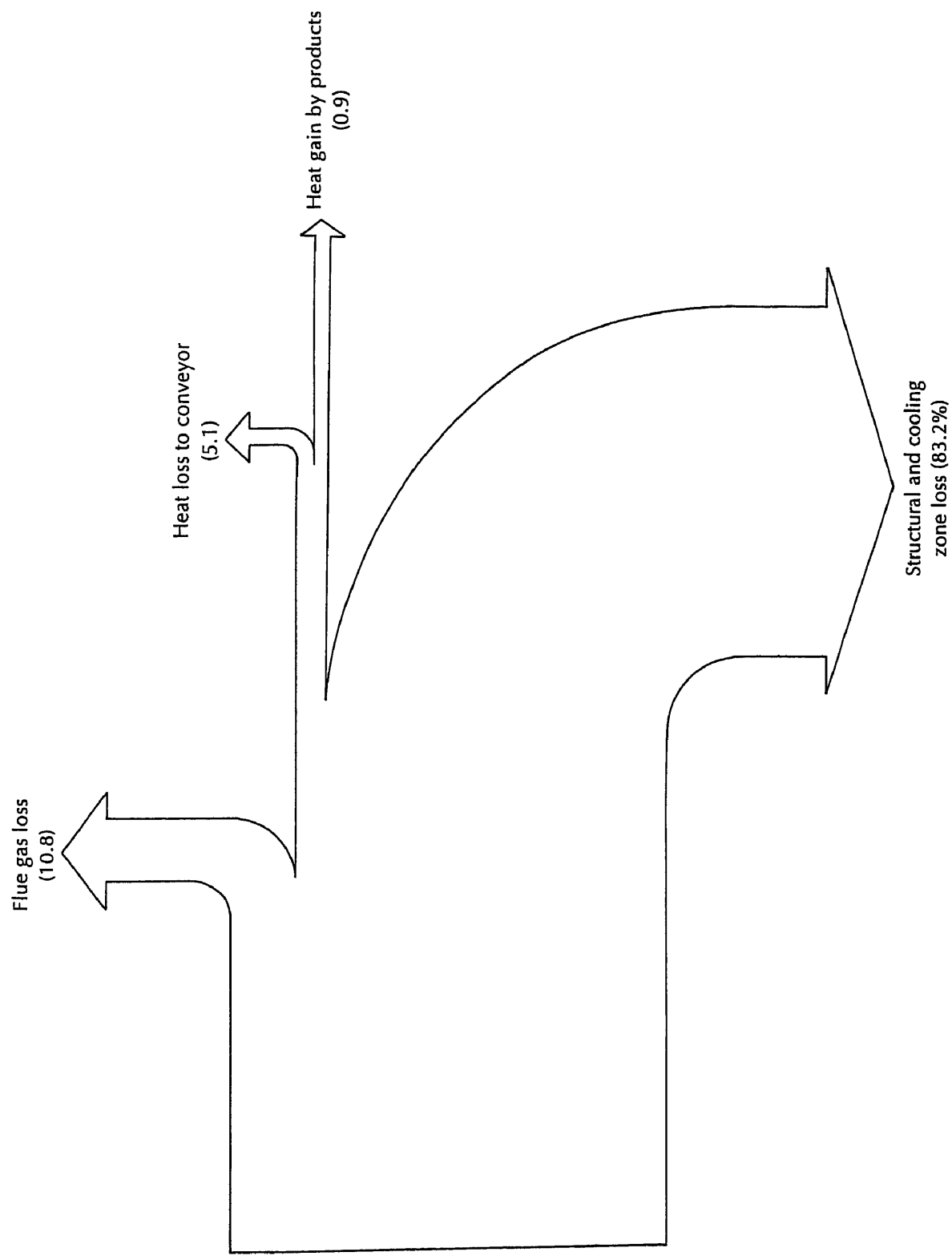


Fig 2.3 Heat balance - Annealing lehr

Table 2.6. Heat balance of the annealing lehr

Heat component	Percentage
Flue gas loss	10.8
Heat loss to conveyor belt	5.1
Residual heat in glass products	0.8
Structural & cooling zone losses	83.2

An analysis of the heat balance indicates that the flue gas loss accounts for 10.8%. About 83% of the heat input to the lehr goes out as structural and cooling zone losses. Some general aspects regarding the operation of annealing lehr is given in **annexure 2.5**.

2.9 Recommendations

2.9.1 Closed conveyor system

At present the existing conveyor system is heated to 500 °C in the heating zone of the lehr, is cooled down in the cooling zone to 100 °C and enters the lehr again at about 50 °C. This has led to substantial loss of fuel input, which accounts for more than 40%. This loss can be avoided if the conveyor is returned internally through the tunnel of the lehr. Internal belt return will assure that the conveyor remains hot at the start of the heating zone, thereby reducing the heat pick-up by the conveyor in the lehr. Although it is difficult to estimate the temperature of the conveyor at the front end of the lehr in case of internal belt return system, a moderate temperature of 300 °C is assumed to demonstrate the savings. The above modification would lead to a fuel saving of 21 kL of kerosene per annum, equivalent to a monetary saving of Rs 84,000.

The possibility of converting single conveyor system to a split system can also be examined. In the split conveyor system, there can be two separate conveyors, one for the heating zone and the second for the cooling zone. This will help in reducing the mass of the conveyor material circulating within the heating zone which acts as a heat sink.

2.9.2 Reduction of structural heat loss

The top and side surfaces of the lehr are not insulated. The bare metallic surfaces are exposed to the atmosphere and has led to high structural losses. By insulating the hot bare surfaces with low thermal mass materials such as ceramic fibre, the structural losses can be brought down by at least 25%.

2.9.3 Compressors

There are two compressors of Kirloskar make in the plant. One compressor is kept as a standby which runs on D.G. set. The regular compressor is run by a 37 kW slip ring motor. The motor was found to be loaded to an optimum level of 82%. The inlet air temperature to the compressor was measured and was found to be 42 °C as against the ambient temperature of 38 °C. The higher inlet air temperature is due to poor ventilation in the compressor room. It should be noted for every 4 °C rise in inlet air temperature, the electricity consumption also increases by 1%. By extending the inlet air duct to draw cooler ambient air, it is possible to bring down the inlet air temperature and hence the electrical energy consumption. The modification which can be carried out at a marginal investment is expected to save annually 2,100 kWh of electricity.

2.10 Conclusion

The most energy intensive operation in the unit are melting and annealing accounting for nearly 95% of the total energy consumption in the plant. The melting efficiency of the tank furnace was found to be 21.3% with a specific energy consumption of 2.1 Gcal/tonne of glass melt. The various energy conservation measures suggested for improving performance of the melting furnace are: (i) excess air optimisation, (ii) waste heat recovery, (iii) improved insulation, (iv) cullet preheating and (v) oxygen enrichment. Since the scale of operation is relatively small, the feasibility of the last two options needs to be specifically worked out in consultation with a glass technologist. The performance of the annealing lehr can be improved with better insulation and internal belt return. Apart from the measures listed above, it is strongly felt that the unit must have some basic instrumentation facility for flue gas analysis, measurement of melt level, etc. to have a close control on furnace operation.

SHRIRAM INSTITUTE FOR INDUSTRIAL RESEARCH

(A UNIT OF SHRIRAM SCIENTIFIC & INDUSTRIAL RESEARCH FOUNDATION, DELHI)
19, UNIVERSITY ROAD, DELHI-110007.

Telegram : 'SRISANDHAN'

Telephone : 7257267

Telex : 031-78051

Fax : 91-11-7257676

E-Mail; Internet: delhi. srifir @ access.net.in

Issued to :

Tata Energy Research Institute (TERI),
India Habitate Centre (D.S. Block),
Lodhi Road, New Delhi..

TEST CERTIFICATE



No. 146779 406-024-0163

Date: 21.06.94

Ks

Your Ref. No.: --

Date: 7.6.94

KIND ATTN.: MR. SOBHANBABU

Sample Particulars:

One sample of R.F.O., was received.

TEST RESULTS

[As received basis]

S.No. Tests	Test Value
1. Carbon content, % by mass	83.0
2. Hydrogen content, % by mass	11.3
3. Sulphur content, % by mass	3.1
4. Gross calorific cals/gm	10,450

COPY

* * * * *

AUTHORISED SIGNATORY

- NOTE
1. The result listed refer only to the tested samples and applicable parameters. Endorsement of products is neither inferred nor implied.
 2. Total liability of our Institute is limited to the invoiced amount.
 3. Samples will be destroyed after one month from the date of issue of test certificate unless otherwise specified.
 4. This report is not to be reproduced without permission in writing and cannot be used as an evidence in the Court of Law and should not be used in any advertising media without permission in writing.

Annexure 2.2

Heat balance: Oil-fired tank furnace

Heat input

Fuel (R.F.O.) consumption	=	208 kg/hr
Gross calorific value of R.F.O.	=	10,450 kcal/kg
Total heat input	=	21,73,600 kcal/hr

Heat distribution

(1) Flue gas loss

(a) Dry flue gas loss

Oxygen content in flue gas	=	3.5%
Excess air level	=	19%
Temperature of flue gases at regenerator outlet	=	400 °C
Sensible heat in dry flue gas	=	3,03,246 kcal/hr
Quantity of air infiltrated to regenerator	=	93 kg/hr
Heat taken by infiltrated air	=	8,455 kcal/hr
Total heat carried by dry flue gas	=	3,11,701 kcal/hr
Percentage dry flue gas loss	=	14.3%

(b) Heat loss due to hydrogen in fuel

Hydrogen content of fuel	=	0.057 kmol/kg fuel
Quantity of hydrogen in fuel	=	11.75 kmol/hr
Heat taken by hydrogen in fuel	=	1,50,408 kcal/hr
Percentage heat loss due to hydrogen in fuel	=	6.9%

(c) Heat loss due to moisture in fuel

Moisture content of fuel	=	0.001 kmol/kg fuel
Quantity of moisture in fuel	=	0.23 kmol/hr
Heat loss due to moisture in fuel	=	2,958 kcal/hr

Percentage heat loss due to moisture in fuel = 0.1%

(d) Heat loss due to moisture in air

Dry bulb temperature = 39 °C
 Wet bulb temperature = 25 °C
 Molal humidity = 0.024 kmol/kmol dry air
 Moisture in air = 2.78 kmol/hr
 Heat taken by moisture in air = 8,565 kcal/hr
 Percentage heat taken by moisture in air = 0.5%

Flue gas loss (a+b+c+d) = 21.8%

(2) Heat in glass melt

(a) Heat taken by thermo-chemical reaction of glass

Quantity of raw material (excluding cullets) = 417 kg/hr
 Heat of reaction = 127 kcal/kg
 Total heat of reaction = 52,778 kcal/hr
 Percentage heat of reaction = 2.4%

(b) Heat in glass melt

Quantity of glass melt = 1042 kg/hr
 Mean specific heat of glass = 0.25 kcal/kg°C
 Temperature of glass melt = 1470 °C
 Sensible heat in melt = 3,73,698 kcal/hr
 Latent heat of fusion of glass = 34 kcal/kg
 Latent heat in melt = 35,902 kcal/hr
 Total heat in melt = 4,09,599 kcal/hr
 Percentage heat in glass melt = 18.9%

Heat in glass melt (a+b) = 21.3%

(3) *Structural losses*

Structural losses	=	12,37,591 kcal/hr
(by difference)		
Percentage structural losses	=	56.9%

Annexure 2.3

Combustion air flow measurement in oil-fired furnace

Reading (for 30 sec)	Velocity (m/sec)	Air flow rate (m ³ /sec)
315	10.5	0.77
360	12.0	0.88
364	12.1	0.89
341	11.4	0.83
355	11.8	0.86
Average combustion air flow rate		2822 Nm ³ /hr

Annexure 2.4

Heat balance : Annealinglehr

Heat input

Fuel (kerosene) consumption	=	13.4 kg/hr
Gross calorific value of kerosene	=	11,100 kcal/kg
Total heat input	=	1,48,925 kcal/hr

Heat distribution

(1) Flue gas loss

(a) Dry flue gas loss

Oxygen content in flue gas	=	8%
Excess air level	=	57%
Temperature of flue gas at regenerator outlet	=	120 °C
Heat in dry flue gas	=	6,241 kcal/hr
Percentage dry flue gas loss	=	4.2%

(b) Heat loss due to hydrogen in fuel

Hydrogen content of fuel	=	0.07 kmol/kg fuel
	=	0.94 kmol/hr
Heat loss due to hydrogen in fuel	=	9,770 kcal/hr
Percentage heat loss due to hydrogen in fuel	=	6.5%

(c) Heat loss due to moisture in air

Dry bulb temperature	=	35 °C
Wet bulb temperature	=	25 °C
Molal humidity	=	0.02 kmol/kmol dry air
Moisture in air	=	0.21 kmol/hr
Heat loss due to moisture in air	=	143 kcal/hr
Percentage heat loss due to moisture in air	=	0.1%

Flue gas loss (a+b+c)	=	10.8%
-----------------------	---	-------

(2) Heat taken by the conveyor belt

Width of conveyor belt	=	1.52 m
Specific weight of belt	=	25.19 kg/m ²
Speed of conveyor belt	=	0.58 m/min
Weight of conveyor passing per hour	=	1,346 kg
Specific heat of conveyor material	=	0.114 kcal/kg°C
Initial temperature of conveyor	=	50 °C
Final temperature of conveyor	=	100 °C
Heat loss to conveyor system	=	7,669 kcal/hr
Percentage heat loss to conveyor system	=	5.1%

(3) Heat taken by the glass products

Quantity of glass products	=	130 kg/hr
Specific heat of glass	=	0.25 kcal/kg°C
Initial temperature of products	=	70 °C
Final temperature of products	=	80 °C
Heat gain by glass products	=	1,250 kcal/hr
Percentage heat gain by glass products	=	0.8%

(4) Structural & cooling zone losses

Structural & cooling zone losses (by difference)	=	1,23,852 kcal/hr
Percentage structural & cooling zone losses	=	83.2%

Annexure 2.5

Annealing lehr

The annealing lehr may be the source of some of the rejections. Ware will be lost if the correct annealing schedule is not followed. The losses caused by poor annealing may very well occur in subsequent processes e.g. packing.

The need to anneal several different items through the same lehr complicates the annealing process and makes it less energy efficient as the lehr must be set for the worst case. The effect of the glass input temperature is often overlooked. A small item may be relatively cold if hand-conveyed to the lehr and may not attain the necessary temperature if the heating zone is too short. Good temperature control is essential, particularly in the critical cooling zone which can be achieved through good temperature monitoring of various zones. The basic monitoring equipment is relatively inexpensive to purchase and simple to install.

Benefits can accrue by improving the awareness of supervisors and operators to the demands of such critical stages in the production cycle as the annealing process. Short, purpose made training videos have been made with some success on such topics e.g. Glass Fracture Analysis produced by Glass Training Ltd, England.

Source: British Glass Technology, U.K.

Energy audit : Coal fired tank furnace

3.1 Introduction

The unit manufactures a wide range of hollow glassware items. It has a coal-fired, regenerative, tank furnace with a melting capacity of 25 tpd, operating on a continuous basis. Some selected details of the furnace are shown in table 3.1.

Table 3.1. Details of coal fired tank furnace

Furnace type	Coal-fired, regenerative, side-port, tank furnace
Fuel used	Coal
Melting capacity	25 tpd
Fuel consumption	16 tpd
Gasifier type	Conventional, fixed-bed

3.2 Glass melting furnace

The batch charge consists of raw materials such as silica sand, soda ash, calcium carbonate, sodium nitrate, potassium nitrate and cullets. Of the total raw material charge, silica sand accounts for 62%, soda ash 22% and calcium carbonate 8-10%.

The tank furnace is a coal fired, side-port, regenerative type with a melting capacity of 25 tpd. A schematic diagram of the furnace is shown in figure 3.1. The refractory used in the furnace is silliminite. The life of insulation is about one year. There are 13 gathering holes each of 9" x 12" size to draw the glass melt from the working chamber. The temperature of the glass melt is maintained at around 1440 °C. The combustion air, preheated to about 712 °C in the regenerator, meets the fuel in burner port.

The checker structure inside the regenerator is made up of a lattice of refractory bricks. The hot flue gases and the combustion air pass through two separate chambers in the regenerator. A flow reversing valve, which is operated manually, is provided at the regenerator air inlet position, for reversing the flow of combustion air and flue gases after every 20 minutes. The sensible heat in hot flue gases is extracted by the refractory bricks during the passage of flue gases, and is utilised to preheat the incoming combustion air.

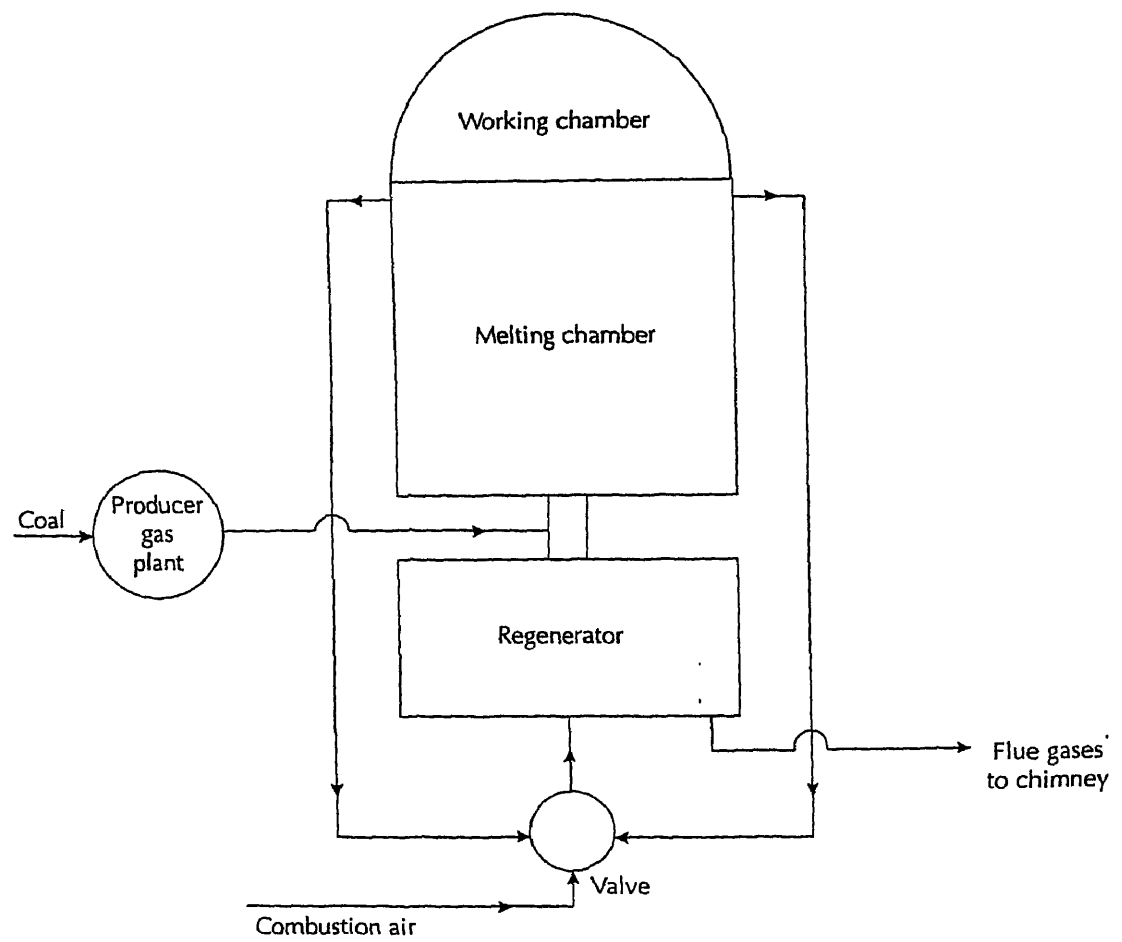


Fig. 3.1 Coal fired tank furnace

The flue gases leave the regenerator at about 630 °C to the stack without any further heat recovery.

3.2.1 Fuel

The fuel used in the melting furnace is producer gas which is generated by gasification of coal. The consumption of coal is about 16 tpd corresponding to a glass melt of 25 tpd. The source of coal is Raniganj collieries. The quality of coal required by the unit is A grade. However, in actual practice, the coal quality received by the unit varies between A and C grades. A sample of coal is collected from the unit as per IS specifications and tested for its constituents. The proximate analysis of coal used in the unit is given in annexure 3.1 and table 3.2.

Table 3.2. Proximate analysis of coal

Characteristics	Percentage (by weight)
Fixed carbon	44.6
Volatile matter	28.6
Ash	22.9
Moisture	3.9
Gross calorific value (kcal/kg)	5680

3.3 Heat balance of the melting furnace

A detailed heat balance of the melting furnace was carried out for evaluating the melting efficiency of the glass furnace and to quantify major energy losses. The following heat components were computed for carrying out the heat balance of the furnace.

- (1) Flue gas loss
- (2) Heat loss to bottom ash
- (3) Heat in glass melt
- (4) Structural losses

The various operating parameters measured and the computation of different heat components as outlined above are given in annexure 3.2. The heat balance of the glass melting furnace is summarised in table 3.3. A sankey diagram showing various heat components associated with the glass melting furnace is given in figure 3.2.

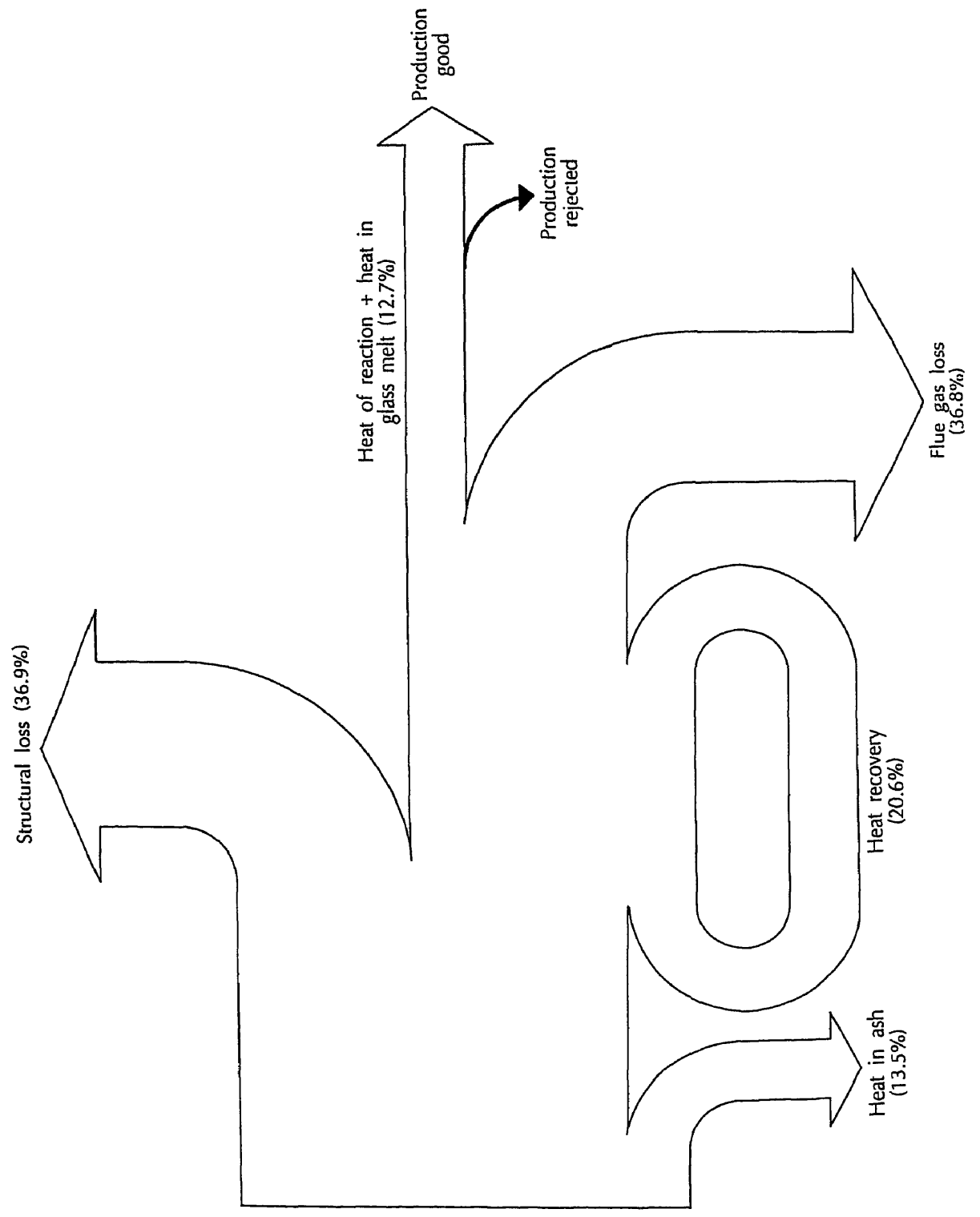


Fig 3.2 Heat balance - Coal fired tank furnace

Table 3.3. Heat balance of coal fired tank furnace

Component	Percentage
Flue gas loss	36.9
Heat loss to bottom ash	13.5
Heat in glass melt	12.7
Structural losses	36.9

The efficiency of the furnace for glass melting is 12.7% of the total fuel heat input. The analysis of heat balance indicates that the major areas of heat loss are (i) flue gas loss (36.9%), (ii) structural losses (36.9%) and (iii) heat loss to bottom ash (13.5%). The fuel to melt ratio was computed to be 0.64 kg/kg. The specific energy consumption was 3.7 Gcal/tonne of melt. *This is approximately twice that of a comparable sized tank furnace operating in UK.*

3.4 Regenerative air preheater

The tank furnace is provided with a regenerative type air preheating system for preheating the combustion air to about 712 °C by utilising the waste heat in the flue gases. About 20.6% of fuel heat input is recovered in the regenerator. The flue gas enters the chimney after the regenerator at 630 °C. A detailed computation of the heat gain by the combustion air in the regenerator is given below.

Quantity of air handed	=	3886 kg/hr
Inlet air temperature to regenerator	=	49 °C
Outlet air temperature from regenerator	=	712 °C
Average specific heat of air	=	8.57 kcal/kmol°K
Heat gain by combustion air	=	778423 kcal/hr
Percentage heat gain by combustion air	=	20.6 %

3.5 Recommendations

Based on the analysis of the energy audit data, a set of measures are suggested which would lead to improvement of energy efficiency of the furnace. The suggested measures are largely similar to the ones discussed for the oil-fired furnace because of similar nature of the major heat losses.

3.5.1 Waste heat recovery

It was found that the combustion air to the furnace is preheated to only 712 °C and the flue gas leaves the regenerator at 630 °C. Incorporation of a secondary heat recovery system to further preheating of combustion air should be examined. Since the sulphur content of coal used is 0.5%, the lower limit to which the flue gas can be cooled (based on the acid dew point temperature of the flue gas) is 120 °C. Assuming that the exit flue gas temperature to be about 160 °C and the effectiveness of the heat exchanger as 0.8, the amount of heat that can be transferred to the combustion air is 0.7 Gcal/hr resulting in a fuel saving of 17%. The equivalent annual coal and monetary savings are 816 tonnes and Rs 12 lakhs respectively.

3.5.2 Structural losses

The structural losses was computed to be 36.9%. The high structural loss was also reflected by the high surface temperatures in different zones of the furnace. It is possible to reduce the structural heat losses by at least 25% with better refractory bricks and insulation material. The corresponding annual coal savings will be 443 tonnes equivalent to a monetary saving of Rs 7.5 lakhs. The use of ceramic fibre blankets as back-up insulating material is also gaining popularity in the glass industry. Because of its light weight, ceramic fibre blanket is ideally suited for crown insulation from the viewpoint of structural stability.

3.5.3 Reduction of unburnt carbon losses

The average carbon content in bottom ash was 29.5% accounting for 13.3% of the fuel input. The unburnt carbon losses are attributed to the outmoded design of the gasifier, improper air-fuel mixing, poor ash handling techniques adopted by the unit and total absence of control system resulting in inefficient use of coal.

The design of gasifier has to be modified for improving the fuel-air mixing and hence the conversion efficiency considerably. Improved ash handling techniques along with better control systems should be adopted for minimising the unburnt losses. The resulting savings will be about 10% of the fuel input. The corresponding fuel savings are 480 tonnes of coal per annum equivalent to a monetary saving of Rs 7.2 lakhs.

3.5.4 Cullet preheating

The sensible heat in flue gases can also be utilised for preheating the cullets before being fed into the furnace. The cullets constitute about 40% of the batch charge. The flue gases can be cooled to 200 °C in the charge preheater. Preheating of the cullets to about 250 °C will result in sensible heat gain equivalent to fuel and monetary savings of 20 tonnes of coal and Rs 30,000 per annum respectively.

Apart from the above measures, further improvement in energy efficiency can be effected by (i) oxygen enrichment (ii) bubble system and (iii) glass level controller, some selected details which have already been discussed in chapter 2.

3.6 Annealing lehr

The annealing lehr is an insulated channel with two zones viz. the heating zone and the cooling zone. The length of the heating zone is 24 ft. Glass products are fed into the heating zone on a conveyor belt which moves at a constant speed through the lehr. The products are heated to a maximum temperature of about 500 °C in the heating zone, soaked at this temperature and subjected to controlled cooling in the cooling zone. It was observed during the plant visit that the flue gases do not pass through chimney; instead they are allowed to pass through entire lehr length and leave the rear end of the lehr at about 83 °C.

3.6.1 Fuel

HSD is used as the fuel used in the annealing lehr and electricity is used for running the conveyor system. The consumption of HSD is 360 lit/day. The characteristics of the fuel used is given in table 3.4.

Table 3.4. Characteristics of HSD

Component	Percentage (by weight)
Carbon	86.0
Hydrogen	13.2
Sulphur	0.8
Gross calorific value (kcal/kg)	10700

3.7 Heat balance of the annealing lehr

A detailed heat balance of the annealing lehr was carried out for evaluating the operating efficiency of the lehr and to quantify major energy losses. The following heat components were computed for carrying out the heat balance.

- (1) Flue gas loss
- (2) Heat loss to conveyor belt
- (3) Residual heat in glass products
- (4) Structural & cooling zone losses

The various operating parameters measured and the computation of different heat components as outlined above are given in **annexure 3.3**. The heat balance of the annealing lehr is summarised in **table 3.5**. A sankey diagram showing various heat components of the lehr is given in **figure 3.3**. An analysis of the heat balance indicates that 77.7% of the heat input is removed as structural and cooling losses.

Table 3.5. Heat balance of annealing lehr

Component	Percentage
Flue gas loss	14.8
Heat in conveyor belt	3.8
Residual heat in glass products	3.7
Structural & cooling zone losses	77.7

3.8 Recommendations

3.8.1 Closed conveyor system

At present the existing conveyor system is heated to 500 °C in the heating zone, cooled down to 85 °C in the cooling zone and enters the lehr again at 60 °C. The heat loss due to cooling of conveyor accounts for 47% of the heat input. This loss can be avoided if the conveyor is returned through the tunnel of the lehr. Internal belt return will assure that the conveyor remains hot at the start of the heating zone thereby reducing the heat pick-up by the conveyor in the lehr. Although it is difficult to estimate the temperature of the conveyor at the front end of the lehr in case of internal belt return system, but a temperature of 300 °C is assumed to demonstrate the savings. The above modification would lead to an annual saving of 20 kl of HSD equivalent to Rs 1.2 lakh.

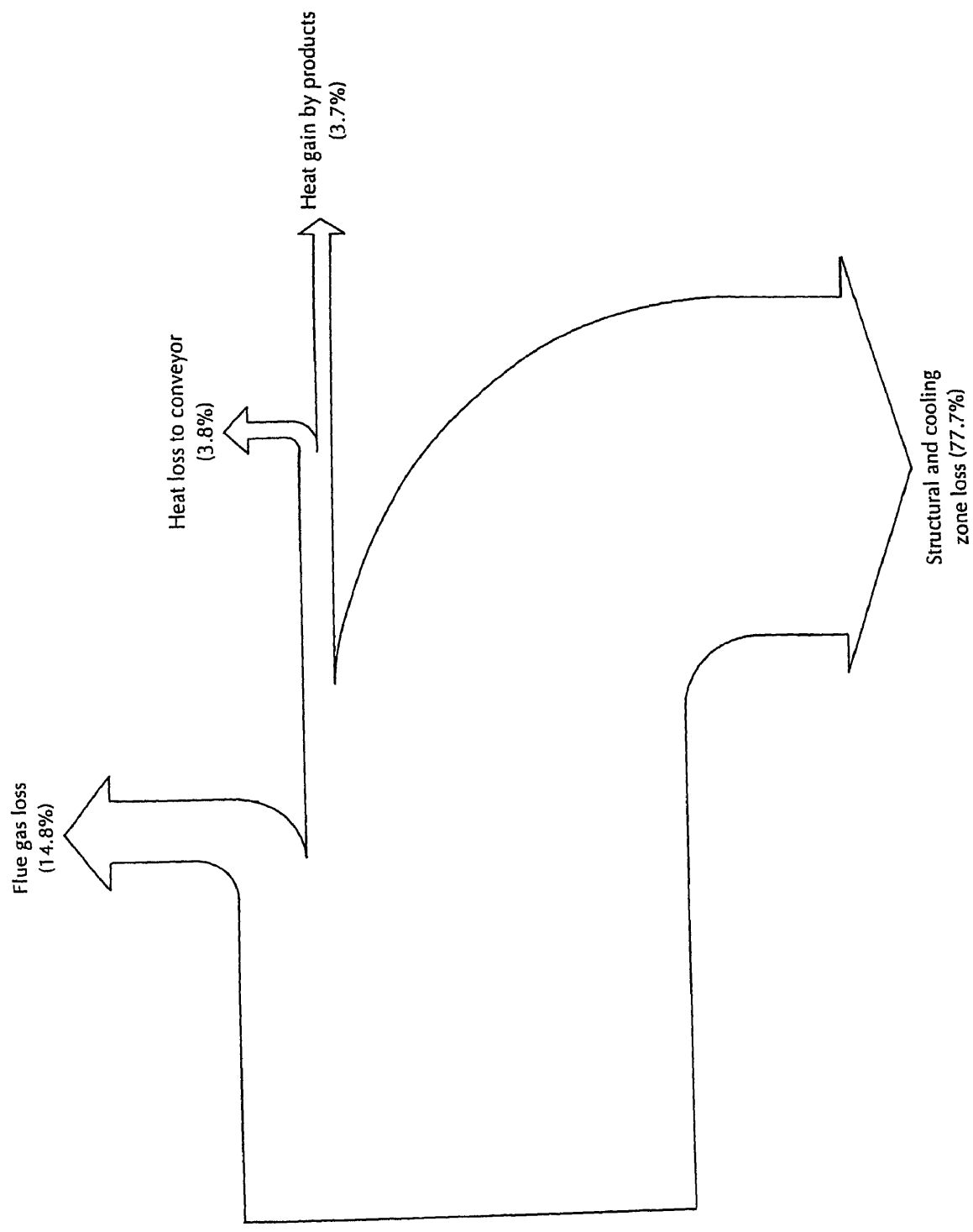


Fig 3.3 Heat balance - Annealing lehr

The possibility of converting single conveyor system to a split system can also be examined. There can be two separate conveyors, one for the heating zone and the second for the cooling zone. This will help in reducing the mass of the conveyor material circulating within the heating zone which acts as a heat sink.

3.8.2 Reduction of structural heat loss

The top and side surfaces of the lehr are not insulated and the bare metallic surfaces are exposed to the atmosphere which has led to high structural loss. By insulating these surfaces, the structural loss can be brought down by at least 25%.

3.9 Conclusion

The melting efficiency of the coal fired tank furnace was found to be 12.7% with a specific energy consumption of 3.6 Gcal/tonne of melt. The major areas of heat loss identified in the glass melting furnace are (i) flue gas loss, (ii) structural losses and (iii) unburnt carbon in bottom ash. In annealing lehr, 47% of the heat is lost in heating and cooling the conveyor system. The measures identified to improve the energy efficiency of the unit include (i) utilisation of waste heat from flue gas of the melting furnace, (ii) reduction of structural loss through improved insulation, (iii) preheating of cullets and (iv) internal belt return in the annealing lehr.

SHRIRAM INSTITUTE FOR INDUSTRIAL RESEARCH

(A UNIT OF SHRIRAM SCIENTIFIC & INDUSTRIAL RESEARCH FOUNDATION, DELHI)
19, UNIVERSITY ROAD, DELHI-110007.

Telegram : 'SRISANDHAN'

Telephone : 7257267

Telex : 031-78051

Fax : 94-11-7257676

E-Mail; Internet: delhi. srifir @ access.net.in

Issued to :

Tata Energy Research Institute (TERI),
India Habitatat Centre (D.S. Block),
Lodhi Road, New Delhi.

TEST CERTIFICATE



No. 146702 406-024-0162

Date: 21.06.94

ICS

Your Ref. No.: ---

Date: 7.6.94

KIND ATTN: MR. SOBHANBABU
Sample Particulars:

One sample of coal, was received.

TEST RESULTS

[As received basis]

S.No.	Tests	Test Value
1.	Proximate Analysis, % by mass	
a)	Moisture content,	3.93
b)	Ash content	22.87
c)	Volatile matter	28.55
d)	Fixed carbon (by diff.)	44.65
2.	Gross calorific value, cala/gm	5680

COPY

* * * * *

AUTHORISED SIGNATORY

NOTE 1. The result listed refer only to the tested samples and applicable parameters. Endorsement of products is neither inferred nor implied.
2. Total liability of our Institute is limited to the invoiced amount.
3. Samples will be destroyed after one month from the date of issue of test certificate unless otherwise specified.
used in any subsequent litigation and cannot be used as an evidence in the Court of Law and should not be permission in writing.

Annexure 3.2

Heat balance : Coal-fired tank furnace

Heat input

Fuel (coal) consumption	=	667 kg/hr
Gross calorific value of coal	=	5,680 kcal/kg
Total heat input	=	37,86,667 kcal/hr

Heat distribution

(1) Flue gas loss

(a) Dry flue gas loss

Oxygen content in flue gas	=	7.8%
Excess air level	=	38%
Temperature of flue gas at regenerator outlet	=	630 °C
Sensible heat in dry flue gas	=	11,29,984 kcal/hr
Quantity of air infiltrated	=	395 kg/hr
Heat taken by infiltrated air	=	59,930 kcal/hr
Total heat carried by dry flue gas	=	11,89,914 kcal/hr
Percentage dry flue gas loss	=	31.4%

(b) Heat loss due to hydrogen in fuel

Hydrogen content of fuel	=	0.016 kmol/kg fuel
Total quantity of hydrogen	=	10.33 kmol/hr
Heat taken by hydrogen	=	1,54,224 kcal/hr
Percentage heat loss due to hydrogen in fuel	=	4.1%

(c) Heat loss due to moisture in fuel

Moisture content of fuel	=	0.002 kmol/kg fuel
Moisture in fuel	=	1.44 kmol/hr
Heat taken by moisture in fuel	=	21,558 kcal/hr

Percentage heat loss due to moisture in fuel = 0.6%

(d) *Heat loss due to moisture in air*

Dry bulb temperature	=	35 °C
Wet bulb temperature	=	25 °C
Relative humidity	=	40%
Molal humidity	=	0.022 kmol/kmol dry air
Moisture in air	=	5.52 kmol/hr
Heat taken by moisture in air	=	28,754 kcal/hr
Percentage heat loss due to moisture in air	=	0.8%
Flue gas loss (a+b+c+d)	=	36.9%

(2) **Heat loss to bottom ash**

(a) *Heat loss due to unburnt carbon in bottom ash*

Total unburnt carbon	=	63 kg/hr
Heat loss due to unburnt carbon	=	5,04,318 kcal/hr
Percentage heat loss due to unburnt carbon in bottom ash	=	13.3%

(b) *Heat loss due to sensible heat in bottom ash*

Quantity of bottom ash	=	212 kg/hr
Temperature of ash	=	200 °C
Specific heat of ash	=	0.25 kcal/kg°C
Sensible heat loss	=	8,759 kcal/hr
Percentage heat loss due to sensible heat in ash	=	0.2%
Heat loss to bottom ash (a+b)	=	13.5%

(3) Heat in glass melt*(a) Heat taken by thermo-chemical reaction of glass*

Quantity of raw material (excluding cullets)	=	625 kg/hr
Heat of reaction	=	127 kcal/kg
Total heat of reaction	=	79,167 kcal/hr
Percentage heat of reaction	=	2.1%

(b) Heat in glass melt

Quantity of glass melt	=	1,042 kg/hr
Mean specific heat of glass	=	0.25 kcal/kg°C
Temperature of glass	=	1440 °C
Sensible heat in glass melt	=	3,65,885 kcal/hr
Latent heat of fusion of glass	=	24 kcal/kg
Latent heat in melt	=	35,902 kcal/hr
Total heat in melt	=	4,01,787 kcal/hr
Percentage heat in glass melt	=	10.6%
Heat in glass melt (a+b)	=	12.7%

(4) Structural heat loss

Structural heat loss (by difference)	=	13,98,186 kcal/hr
Percentage structural heat loss	=	36.9%

Annexure 3.3

Heat balance : Annealing lehr

Heat input

Fuel (H.S.D) consumption	=	360 kg/hr
Gross calorific value of H.S.D.	=	10,700 kcal/kg
Total heat input	=	1,34,820 kcal/hr

Heat distribution

(1) Flue gas loss

(a) Dry flue gas loss

Oxygen content in flue gas	=	2%
Excess air level	=	10%
Temperature of flue gas	=	83 °C
Heat in dry flue gas	=	10,234 kcal/hr
Percentage dry flue gas loss	=	7.5%

(b) Heat loss due to hydrogen in fuel

Hydrogen content of fuel	=	0.066 kmol/kg fuel
Hydrogen content	=	0.83 kmol/hr
Heat loss due to hydrogen in fuel	=	9533 kcal/hr
Percentage heat loss due to hydrogen in fuel	=	7.1%

(c) Heat loss due to moisture in air

Dry bulb temperature	=	35 °C
Wet bulb temperature	=	25 °C
Molal humidity in air	=	0.02 kmol/kmol dry air
Total moisture in air	=	0.14 kmol/hr
Total heat loss due to moisture in air	=	251 kcal/hr
Percentage heat loss due to moisture in air	=	0.2%

Flue gas loss (a+b+c)	=	14.8%
-----------------------	---	-------

(2) Heat loss to conveyor belt

Width of conveyor belt	=	1.52 m
Specific weight of belt	=	25.2 kg/m ²
Speed of conveyor belt	=	0.55 m/min
Area of belt passing	=	50.31 m ² /hr
Weight of conveyor passing	=	1267 kg/hr
Specific weight of conveyor material	=	0.114 kcal/kg°C
Initial temperature of conveyor	=	50 °C
Final temperature of conveyor	=	85 °C
Heat loss to conveyor belt	=	5056 kcal/hr
Percentage heat loss to conveyor belt	=	3.8%

(3) Residual heat in glass products

Quantity of glass products	=	833 kg/hr
Specific heat of glass	=	0.25 kcal/kg°C
Initial temperature of products	=	80 °C
Final temperature of products	=	120 °C
Residual heat in glass products	=	5000 kcal/hr
Percentage residual heat in glass products	=	3.7%

(4) Structural & cooling zone losses

Total structural heat loss (by difference)	=	1,04,762 kcal/hr
Percentage structural heat loss	=	77.7%

Energy audit : Closed pot furnace

4.1 Introduction

The unit manufactures a wide range of glass products such as bulb shells, tubes, glass rods and fancy decorative items. The furnace employed is coal-fired, Japanese closed pot type with a melting capacity of 3 tpd, operating on a continuous basis. A schematic diagram of the pot furnace is shown in figure 4.1. Some selected details of the furnace are given in table 4.1.

Table 4.1. Details of closed pot melting furnace

Furnace type	Japanese, closed pot furnace
Number of pots	12
Melting capacity	3 tpd
Fuel used	Coal
Fuel consumption	5 tpd

The batch charge fed to the furnace pot consists of raw materials such as silica sand and soda ash. Of the total batch charge, silica sand accounts for 70% and soda ash for the remaining 30%. Prior to feeding into the furnace, the raw materials are weighed and blended with other minor batch ingredients as per the requirements. The batch charge is then fed to the pot for melting.

There are 12 pots in the furnace, each carrying a charge weight of 240 kg. The pots, filled with the raw materials, are heated to the required temperature. The total time required for glass melting is 20-22 hours. The temperature of the glass melt is maintained at 1250-1280 °C.

Coal is used as fuel in the melting furnace. The average consumption of coal is 5 tpd. The required coal quality is A grade. However, in actual practice the coal quality received by the unit varies between A and C grades.

The overall rejection rate is between 25-50% of the total glass drawn. Most of the rejections take place at the cutting section. The high rejection rate attributable to the

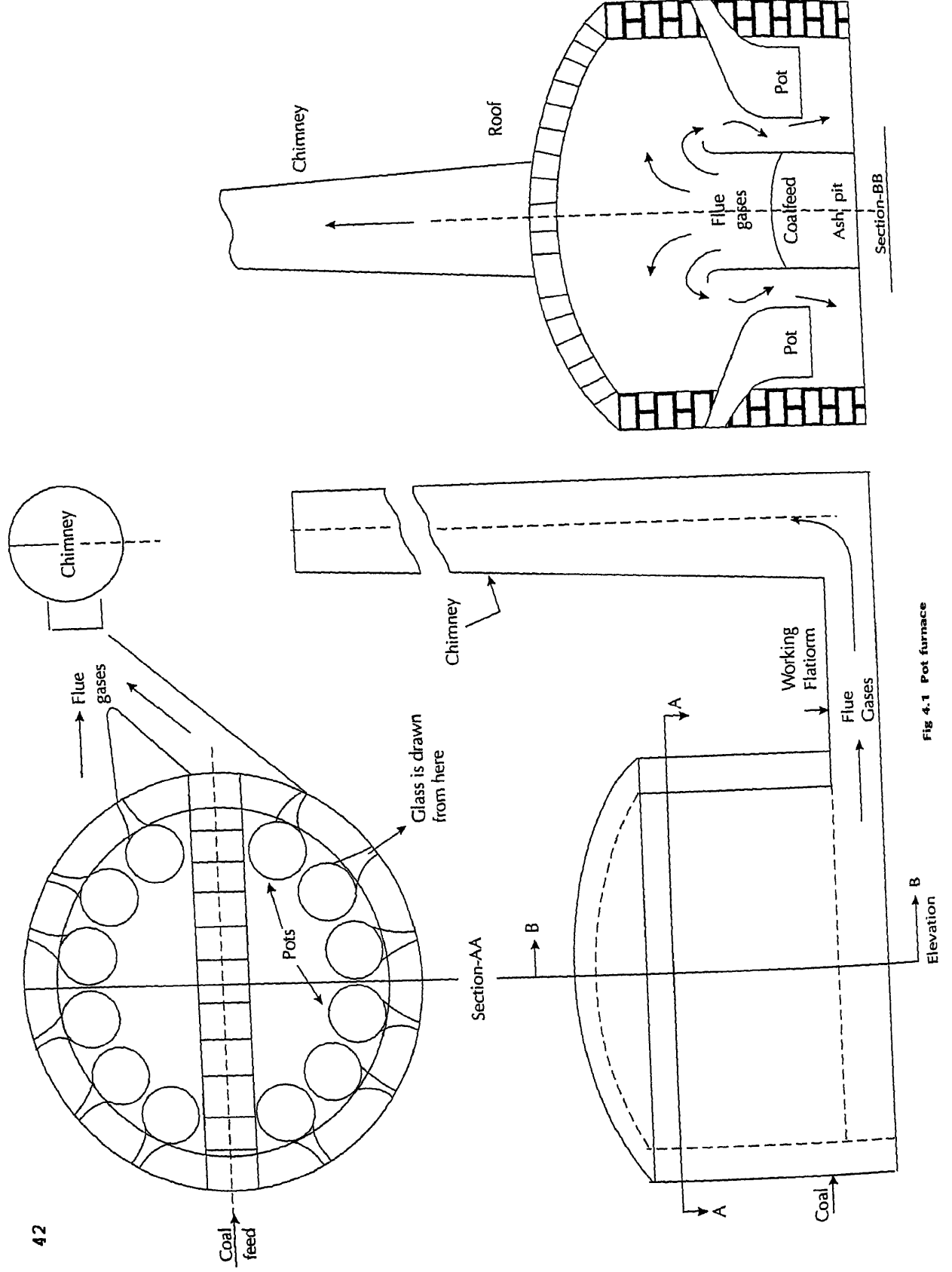


Fig 4.1 Pot furnace

cutting losses, however, is unavoidable. The total production after all the rejections is about 1.5 tpd.

4.2 Heat balance of the melting furnace

A detailed heat balance of the melting furnace was carried out for evaluating the melting efficiency of the glass furnace and to quantify major energy losses. The following heat components were considered for computing the heat balance.

- (1) Flue gas loss
- (2) Heat loss to bottom ash
- (3) Heat in glass melt
- (4) Structural losses

The details of the measurements taken and the computation of different heat components are given in **annexure 4.1**. The summary of the heat balance is furnished in **table 4.2**. A sankey diagram showing various heat components pertaining to the closed pot melting furnace is given in **figure 4.2**.

Table 4.2. Heat balance of closed pot melting furnace

Component	Percentage
Flue gas loss	53.9
Heat loss due to bottom ash	21.4
Heat in glass melt	4.7
Structural losses	20.0

As can be seen from table 4.2, the melting efficiency of the furnace is only 4.7% of the total heat input, which is an extremely low figure. The poor performance of the furnace is also indicated by the low fuel to melt ratio (1.7 kg/kg). The corresponding figure for a typical coal-fired tank furnace is around 0.6 kg/kg. The specific energy consumption was computed to be 9.5 Gcal. The major areas of heat loss are (i) flue gas loss, (ii) heat loss to bottom ash and (iii) structural heat loss, together accounting for 95.3% of the total energy input.

4.3.3 Reduction of unburnt carbon losses

The unburnt carbon content in the bottom ash was found to be very high being found in some samples (41.1%). The average carbon content in bottom ash was around 16.2%, accounting for 20.7% of the input heat being lost through this route. The unburnt carbon loss is attributed to improper air-fuel mixing resulting in inefficient combustion of fuel and poor ash handling techniques adopted by the plant.

The furnace design has to be modified so as to improve the fuel-air mixing considerably to increase the combustion efficiency. Improved ash handling techniques should be adopted for minimising the loss of carbon. The resultant saving could be anywhere between 7-10% of fuel amounting to an annual monetary saving of Rs 2 lakhs.

4.3.4 Use of better quality pots

The pots used in the furnace are procured from local market and the quality of the pots are far from satisfactory. The average pot life was reported to be only 20 days with numerous cases being registered where pot failure occurred within 3-4 days. Each pot-failure means a wastage over 0.3 Gcal of heat and this is one area which presents considerable scope for improvement. This can be accomplished by either upgrading the technology level of the local pot manufacturers or motivating some established refractory manufacturers to supply good quality pots to the Firozabad glass units. It should be noted that sometime back Tata Refractories Limited, Belpahar carried out a feasibility study of manufacturing pots suitable for the Firozabad glass industry but nothing has been materialised so far.

4.4 Conclusion

The heat balance of the closed pot furnace shows that the melting efficiency is only 4.7 % and the fuel to melt ratio is 1.7 kg/kg. The corresponding figures for a coal fired tank furnace are 13% and 0.6 kg/kg. The specific energy consumption works out to 9.5 Gcal. The high energy consumption of the unit is attributed to (i) high heat loss in flue gas (53.9%) due to high flue gas temperature, (ii) heat loss to bottom ash (21.4%) due to poor combustion/ash-handling techniques and (iii) structural heat loss (20%) due to poor quality of insulation. The measures identified for minimising the energy wastages are combustion air preheating, better combustion systems for the furnace and use of better refractory & insulation materials. These measures along with good house-keeping would help in reducing the specific energy consumption of the unit to a minimum of 6.0 Gcal.

Annexure 4.1

Heat balance : Closed pot glass melting furnace

Heat input

Fuel (coal) consumption	=	208 kg/hr
Gross calorific value of coal	=	5680 kcal/kg
Total heat input	=	11,83,333 kcal/hr

Heat distribution

(1) Flue gas loss

(a) Dry flue gas loss

Oxygen content in flue gas	=	6.5%
Excess air level	=	36%
Flue gas temperature at outlet	=	959 °C
Sensible heat in dry flue gas	=	5,57,882 kcal/hr
Percentage dry flue gas loss	=	47.1%

(b) Heat loss due to hydrogen in fuel

Hydrogen content in fuel	=	0.016 kmol/kg fuel
Total hydrogen content	=	3.23 kmol/hr
Heat taken by hydrogen in fuel	=	58,698 kcal/hr
Percentage heat loss due to hydrogen in fuel	=	5.0%

(c) Heat loss due to moisture in fuel

Moisture content of fuel	=	0.002 kmol/kg fuel
Total moisture in fuel	=	0.45 kmol/hr
Heat taken by moisture in fuel	=	8205 kcal/hr
Percentage heat loss due to moisture in fuel	=	0.7%

(d) Heat loss due to moisture in air

Dry bulb temperature	=	40 °C
Wet bulb temperature	=	28 °C
Molal humidity	=	0.02 kmol/kmol dry air
Moisture in air	=	1.55 kmol/hr

4.3.3 Reduction of unburnt carbon losses

The unburnt carbon content in the bottom ash was found to be very high being found in some samples (41.1%). The average carbon content in bottom ash was around 16.2%, accounting for 20.7% of the input heat being lost through this route. The unburnt carbon loss is attributed to improper air-fuel mixing resulting in inefficient combustion of fuel and poor ash handling techniques adopted by the plant.

The furnace design has to be modified so as to improve the fuel-air mixing considerably to increase the combustion efficiency. Improved ash handling techniques should be adopted for minimising the loss of carbon. The resultant saving could be anywhere between 7-10% of fuel amounting to an annual monetary saving of Rs 2 lakhs.

4.3.4 Use of better quality pots

The pots used in the furnace are procured from local market and the quality of the pots are far from satisfactory. The average pot life was reported to be only 20 days with numerous cases being registered where pot failure occurred within 3-4 days. Each pot-failure means a wastage over 0.3 Gcal of heat and this is one area which presents considerable scope for improvement. This can be accomplished by either upgrading the technology level of the local pot manufacturers or motivating some established refractory manufacturers to supply good quality pots to the Firozabad glass units. It should be noted that sometime back Tata Refractories Limited, Belpahar carried out a feasibility study of manufacturing pots suitable for the Firozabad glass industry but nothing has been materialised so far.

4.4 Conclusion

The heat balance of the closed pot furnace shows that the melting efficiency is only 4.7 % and the fuel to melt ratio is 1.7 kg/kg. The corresponding figures for a coal fired tank furnace are 13% and 0.6 kg/kg. The specific energy consumption works out to 9.5 Gcal. The high energy consumption of the unit is attributed to (i) high heat loss in flue gas (53.9%) due to high flue gas temperature, (ii) heat loss to bottom ash (21.4%) due to poor combustion/ash-handling techniques and (iii) structural heat loss (20%) due to poor quality of insulation. The measures identified for minimising the energy wastages are combustion air preheating, better combustion systems for the furnace and use of better refractory & insulation materials. These measures along with good house-keeping would help in reducing the specific energy consumption of the unit to a minimum of 6.0 Gcal.

Annexure 4.1

Heat balance : Closed pot glass melting furnace

Heat input

Fuel (coal) consumption	=	208 kg/hr
Gross calorific value of coal	=	5680 kcal/kg
Total heat input	=	11,83,333 kcal/hr

Heat distribution

(1) Flue gas loss

(a) Dry flue gas loss

Oxygen content in flue gas	=	6.5%
Excess air level	=	36%
Flue gas temperature at outlet	=	959 °C
Sensible heat in dry flue gas	=	5,57,882 kcal/hr
Percentage dry flue gas loss	=	47.1%

(b) Heat loss due to hydrogen in fuel

Hydrogen content in fuel	=	0.016 kmol/kg fuel
Total hydrogen content	=	3.23 kmol/hr
Heat taken by hydrogen in fuel	=	58,698 kcal/hr
Percentage heat loss due to hydrogen in fuel	=	5.0%

(c) Heat loss due to moisture in fuel

Moisture content of fuel	=	0.002 kmol/kg fuel
Total moisture in fuel	=	0.45 kmol/hr
Heat taken by moisture in fuel	=	8205 kcal/hr
Percentage heat loss due to moisture in fuel	=	0.7%

(d) Heat loss due to moisture in air

Dry bulb temperature	=	40 °C
Wet bulb temperature	=	28 °C
Molal humidity	=	0.02 kmol/kmol dry air
Moisture in air	=	1.55 kmol/hr

Heat loss due to moisture in air	=	13,150 kcal/hr
Percentage heat loss due to moisture in air	=	1.1%
Flue gas loss (a+b+c+d)	=	53.9%

(2) Heat loss to bottom ash

(a) Heat loss due to unburnt carbon in bottom ash

Ash content of coal	=	0.25 kg/kg coal
Total unburnt carbon	=	30 kg/hr
Heat loss due to unburnt carbon	=	2,44,549 kcal/hr
Percentage heat loss due to unburnt carbon	=	20.7%

(b) Heat loss due to sensible heat in bottom ash

Total quantity of bottom ash	=	187.5 kg/hr
Temperature of bottom ash	=	220°C
Specific heat of ash	=	0.25 kcal/kg°C
Sensible heat in bottom ash	=	8438 kcal/hr
Percentage heat loss due to sensible heat in ash	=	0.7%
Heat loss to bottom ash (a+b)	=	21.4%

(3) Heat in glass melt

(a) Heat of thermo-chemical reaction

Quantity of raw material (excluding cullets)	=	100 kg/hr
Heat of reaction	=	127 kcal/kg
Total heat of reaction	=	12,667 kcal/hr
Percentage heat of thermo-chemical reaction	=	1.1%

(b) Heat in glass melt

Quantity of glass melt	=	125 kg/hr
Mean specific heat of glass	=	0.25 kcal/kg°C
Temperature of glass melt	=	1280 °C
Sensible heat in melt	=	38,750 kcal/hr
Latent heat of fusion of glass	=	34 kcal/kg
Latent heat in melt	=	4308 kcal/hr
Heat in glass melt	=	43,058 kcal/hr

Percentage heat in glass melt = 3.6%

Heat in glass melt (a+b) = 4.7%

(4) Structural losses

Structural heat loss = 2,36,688 kcal/hr
(by difference)

Percentage structural losses = 20.0%

Heat loss due to moisture in air	=	13,150 kcal/hr
Percentage heat loss due to moisture in air	=	1.1%

Flue gas loss (a+b+c+d)	=	53.9%
-------------------------	---	-------

(2) Heat loss to bottom ash

(a) Heat loss due to unburnt carbon in bottom ash

Ash content of coal	=	0.25 kg/kg coal
Total unburnt carbon	=	30 kg/hr
Heat loss due to unburnt carbon	=	2,44,549 kcal/hr
Percentage heat loss due to unburnt carbon	=	20.7%

(b) Heat loss due to sensible heat in bottom ash

Total quantity of bottom ash	=	187.5 kg/hr
Temperature of bottom ash	=	220°C
Specific heat of ash	=	0.25 kcal/kg°C
Sensible heat in bottom ash	=	8438 kcal/hr
Percentage heat loss due to sensible heat in ash	=	0.7%
Heat loss to bottom ash (a+b)	=	21.4%

(3) Heat in glass melt

(a) Heat of thermo-chemical reaction

Quantity of raw material (excluding cullets)	=	100 kg/hr
Heat of reaction	=	127 kcal/kg
Total heat of reaction	=	12,667 kcal/hr
Percentage heat of thermo-chemical reaction	=	1.1%

(b) Heat in glass melt

Quantity of glass melt	=	125 kg/hr
Mean specific heat of glass	=	0.25 kcal/kg°C
Temperature of glass melt	=	1280 °C
Sensible heat in melt	=	38,750 kcal/hr
Latent heat of fusion of glass	=	34 kcal/kg
Latent heat in melt	=	4308 kcal/hr
Heat in glass melt	=	43,058 kcal/hr

Percentage heat in glass melt = 3.6%

Heat in glass melt (a+b) = 4.7%

(4) Structural losses

Structural heat loss = 2,36,688 kcal/hr
(by difference)

Percentage structural losses = 20.0%

Energy audit : Open pot furnace

5.1 Introduction

The unit manufactures bangles. It employs a coal-fired, open pot furnace having a melting capacity of 5 tpd. Some selected details of the furnace are given in table 5.1.

Table 5.1. Details of open pot glass melting furnace

Furnace type	Open pot furnace
Number of pots	10
Melting capacity	5 tpd
Fuel used	Coal
Fuel consumption	4 tpd

The batch charge for glass making consists of raw materials such as silica sand and soda ash. Prior to feeding into the pots, these raw materials are weighed and blended with other minor batch ingredients as per the requirement.

There are 10 pots in the furnace, each carrying a charge of about 480 kg. The pots filled with the raw material are heated to the required temperature of 1250-1280°C by burning coal. The total time required for melting is 20-22 hours. The average coal consumption is 4 tpd.

5.2 Heat balance of the glass melting furnace

A detailed heat balance of the melting furnace was carried out with a view to evaluate the melting efficiency of the furnace and to quantify major energy losses. The following heat components were computed for carrying out the heat balance.

- (1) Flue gas loss
- (2) Heat loss to bottom ash
- (3) Heat in glass melt
- (4) Structural losses

The details of the measurements taken and the computation of different heat components are given in **annexure 5.1** and the summary of the results is furnished in **table 5.2**. A sankey diagram showing different heat components is given in **figure 5.1**.

Table 5.2. Heat balance of open pot furnace

Heat component	Percentage
Flue gas loss	34.4
Heat loss to bottom ash	31.9
Heat in glass melt	9.8
Structural losses	23.9

As can be seen from table 5.2, the efficiency of the melting furnace was 9.8% of the total heat input. The fuel to melt ratio was 0.8 kg/kg; the specific energy consumption was computed to be 4.5 Gcal. The major areas of heat loss are (i) flue gas loss, (ii) heat loss to bottom ash and (iii) structural losses, together accounting for 90.2% of the total heat input.

5.3 Recommendations

The major causes of energy inefficiency in a open pot furnace are similar to that observed for a closed pot furnace as discussed in chapter 4. The recommendations to improve the energy efficiency of the open pot furnace are, therefore, similar to the ones discussed for the closed pot furnace.

5.3.1 Air preheating

The oxygen content in flue gases is 8.5% and the corresponding excess air level is 51%. The flue gas temperature at the outlet of the furnace is 580 °C. The corresponding flue gas loss is 34.4%. This heat loss can be attributed mainly to high temperature of flue gases which leave the furnace without any heat recovery.

Incorporation of an air preheater for heating the combustion air by utilising the waste heat in flue gases shall be examined. The lower limit of the flue gas temperature up to which it can be cooled in the air preheater is determined by the acid dew point temperature of the flue gases. The coal used has only 0.5% of sulphur and the corresponding dew point temperature is about 120 °C. To avoid any corrosion problems, the flue gases can be allowed to cool down to around 160 °C in the heat recovery system. The resulting high preheat air temperatures will increase the flame temperature, thereby

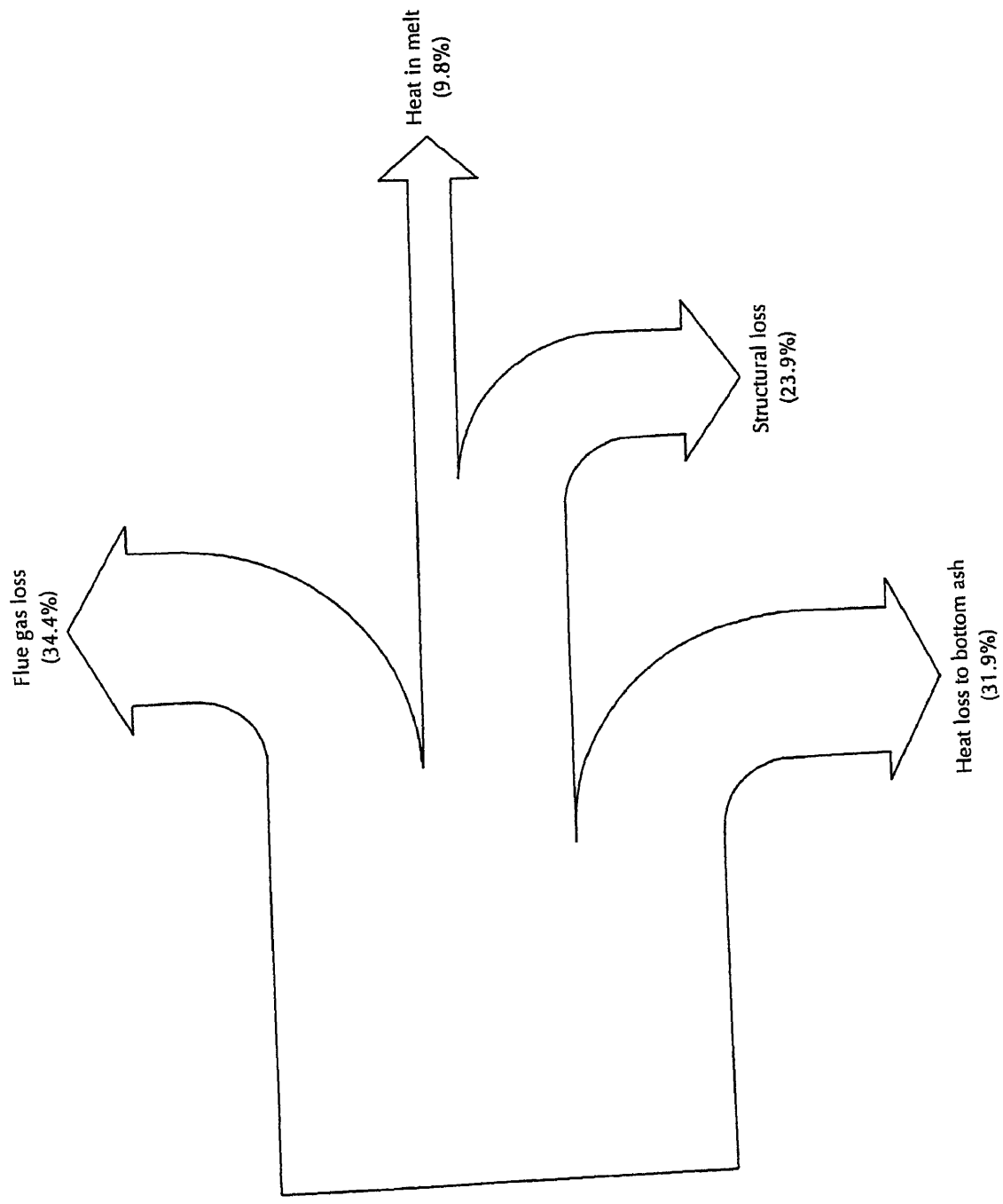


Fig 5.1 Heat balance - Open pot furnace

improving the melting efficiency. Fuel savings of the order of 10% with a corresponding annual monetary savings of Rs 2 lakh can be achieved by preheating the combustion air with flue gases.

5.3.2 Structural losses

The structural losses, computed as the difference of heat input and sum of the heat losses, was 23.9%. The high structural loss is mainly because ordinary clay bricks are used in the furnace and the surfaces are not properly insulated. Use of insulation materials like ceramic fibres and better refractory bricks with low thermal conductivity is recommended to reduce the structural heat loss. The use of ceramic fibre blankets especially in the crown needs serious consideration as this will reduce the heat loss without substantially increasing the structural load. These modifications, however, can only be carried out when the furnace is reconstructed as improving the insulation in the existing system will lead to thermal stresses and possible failure of the structure.

5.3.3 Reduction of unburnt carbon loss

The unburnt carbon content in the furnace bottom ash was found to be very high. The average carbon content in bottom ash was 24.5%, accounting for 31.3% of the input energy being lost through this route. The loss is attributed to improper air-fuel mixing resulting in inefficient combustion of fuel coupled with poor ash handling techniques adopted by the plant, which can only be overcome by better furnace design so as to improve the fuel-air mixing considerably to increase the combustion efficiency. The resultant fuel saving will be about 15% of the input. This corresponds to an annual monetary saving of Rs 3 lakh.

5.3.4 Use of better quality pots

The pots used in the furnace are procured from local market and the quality of the pots are far from satisfactory. The average pot life was reported to be only 20 days with numerous cases being registered where pot failure occurred within 3-4 days. Each pot-failure means a wastage over 0.1 Gcal of energy. The subject on pot quality has already been discussed in section 4.3.4.

5.4 Conclusion

The heat balance of the furnace shows that the melting efficiency is only 9.8% and the fuel to melt ratio is 0.8. The specific energy consumption works out to be 4.5 Gcal. The high energy consumption at the unit is attributed to (i) sensible heat loss in flue gas (34.4%), due to high flue gas temperature, (ii) unburnt carbon loss (31.3%) due to poor combustion/ash handling techniques and (iii) structural losses (23.9%) due to improper insulation and better refractory material. The measures identified for minimising these energy wastages are combustion air preheating, better combustion systems for the furnace and use of better refractory & insulation materials. These measures along with good housekeeping will help in reducing the specific energy consumption of the plant to about 3.5 Gcal.

Annexure 5.1

Heat balance : Open pot furnace

Heat input

Fuel (coal) consumption	=	167 kg/hr
Gross calorific value of coal	=	5680 kcal/kg
Total heat input	=	9,46,667 kcal/hr

Heat distribution

(1) Flue gas loss

(a) Dry flue gas loss

Oxygen content in flue gas	=	8.5%
Excess air level	=	57%
Temperature of flue gas	=	580 °C
Heat in dry flue gas	=	3,31,044 kcal/hr
Percentage dry flue gas loss	=	29.2%

(b) Heat loss due to hydrogen in fuel

Hydrogen content in fuel	=	0.016 kmol/kg fuel
Total hydrogen content	=	3.09 kmol/hr
Heat loss due to hydrogen in fuel	=	44,551 kcal/hr
Percentage heat loss due to hydrogen in fuel	=	3.9%

(c) Heat loss due to moisture in fuel

Moisture content of fuel	=	0.002 kmol/kg fuel
Total moisture in fuel	=	0.43 kmol/hr
Heat loss due to moisture in fuel	=	6228 kcal/hr
Percentage heat loss due to moisture in fuel	=	0.5%

(d) Heat loss due to moisture in air

Dry bulb temperature	=	42 °C
Wet bulb temperature	=	26 °C
Molal humidity	=	0.023 kmol/kmol dry air
Total moisture in air	=	1.84 kmol/hr

Heat loss due to moisture in air	=	8622 kcal/hr
Percentage heat loss due to moisture in air	=	0.8%

Flue gas loss (a+b+c+d)	=	34.4%
-------------------------	---	-------

(2) Heat loss to bottom ash

(a) Heat loss due to unburnt carbon in bottom ash

Ash content of coal	=	0.25 kg/kg coal
Total unburnt carbon	=	44 kg/hr
Heat loss due to unburnt carbon	=	3,54,476 kcal/hr
Percentage heat loss due to unburnt carbon in ash	=	31.2%

(b) Heat loss due to sensible heat in bottom ash

Quantity of bottom ash	=	179 kg/hr
Temperature of bottom ash	=	200 °C
Specific heat of ash	=	0.25 kcal/kg°C
Sensible heat in bottom ash	=	7099 kcal/hr
Percentage heat loss due to sensible heat in ash	=	0.7%

Heat loss to bottom ash (a+b)	=	31.9%
-------------------------------	---	-------

(3) Heat in glass melt

(a) Heat of thermo-chemical reaction

Quantity of raw material (excluding cullets)	=	167 kg/hr
Heat of reaction	=	127 kcal/kg
Total heat of reaction	=	21,111 kcal/hr
Percentage heat of reaction	=	2.2%

(b) Heat in glass melt

Quantity of glass melt	=	208 kg/hr
Mean specific heat of glass	=	0.25 kcal/kg°C
Temperature of melt	=	1280 °C
Sensible heat in melt	=	64,479 kcal/hr
Latent heat of fusion of glass	=	34 kcal/kg
Latent heat in melt	=	7180 kcal/hr

Heat in glass melt	=	71,659 kcal/hr
Percentage heat in glass melt	=	7.6%

Heat in glass melt (a+b)	=	9.8%
--------------------------	---	------

(5) Structural losses

Structural losses (by difference)	=	2,26,200 kcal/hr
Percentage structural losses	=	23.9%

Energy audit : Muffle furnace (Pakai bhatti)

6.1 Introduction

The unit employs a coal-fired muffle furnace for baking bangles. A visit to the unit was undertaken in order to study the heating cycle, the energy consumption pattern and to measure energy related parameters. A heat balance of the furnace was carried out to evaluate the operating efficiency, to quantify major heat losses and to identify areas where there is scope for minimising energy wastage. **Table 6.1** shows some selected details of the muffle furnace.

Table 6.1. Details of muffle furnace

Furnace type	Muffle furnace
Product handling capacity	32 kg/hr
Fuel used	Coal
Fuel consumption	500 kg/day

The furnace has dimensions of 65 x 56 x 54 inch. The furnace has three horizontal tiers, each of 3.5 x 28 inch size, to heat the bangles to the required temperature. A schematic diagram of the muffle furnace is shown in **figure 6.1**. The temperatures measured in the bottom, middle and the top tiers were 480 °C, 440 °C and 410 °C respectively. The bangles are arranged on trays and are placed in the bottom tier first, then shifted to the middle and finally to the top tier. In each tier the tray is kept for approximately 3 minutes duration. About 32 kg of bangles are baked an hour. Coal is burnt at the bottom of the furnace and flue gases flow upward around the tiers finally leaving the furnace at 710 °C without any heat recovery. The average coal consumption is 500 kg/day. The furnace is operated on natural draft.

6.2 Heat balance of muffle furnace

A detailed heat balance of muffle furnace was carried out for evaluating the operating efficiency of the furnace and to quantify major energy losses. The following heat components were considered for computing the heat balance.

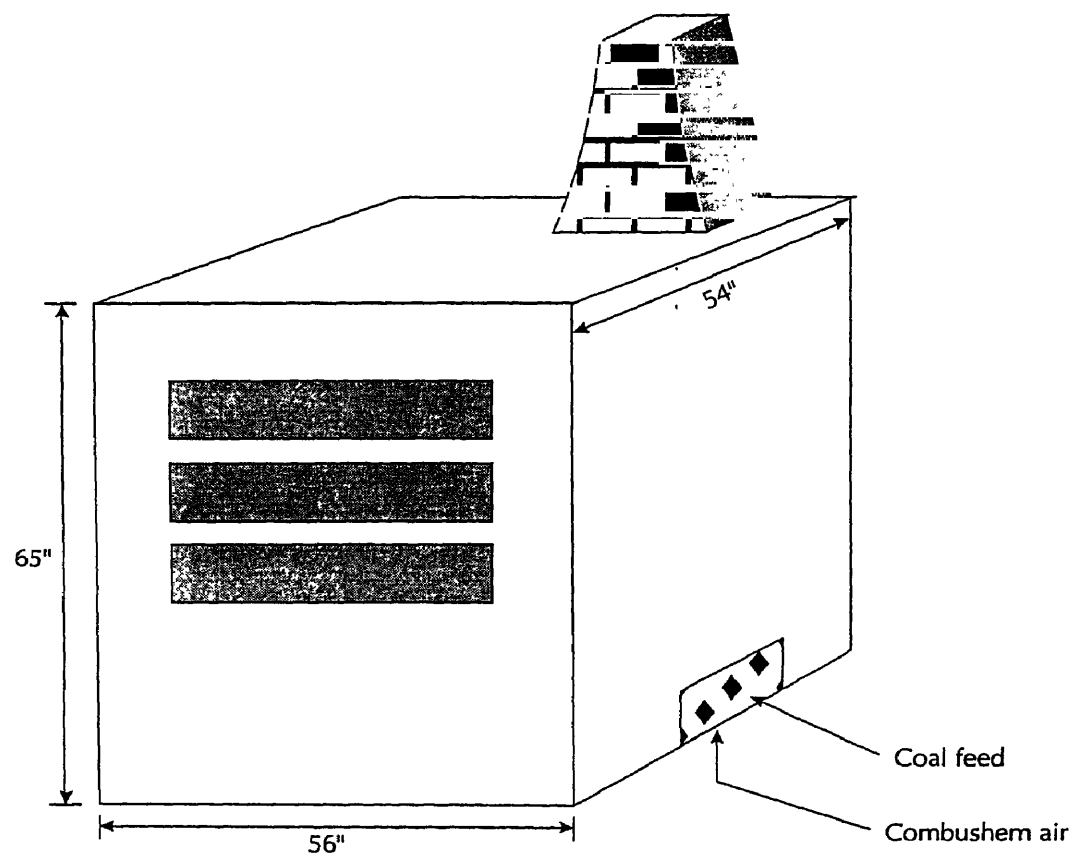


Fig. 6.1 Muffle furnace

- (1) Flue gas loss
- (2) Heat loss to bottom ash
- (3) Heat gain by bangles
- (4) Heat loss to trays
- (5) Structural losses

The measurements taken and the detailed computation of different heat components are given in **annexure 6.1**. A summary of the heat balance is furnished in **table 6.2**. A sankey diagram showing various heat components of the muffle furnace is given in **figure 6.2**.

Table 6.2. Heat balance of muffle furnace

Component	Percentage
Flue gas loss	46.2
Heat loss to bottom ash	35.4
Heat gain by bangles	3.1
Heat loss to trays	4.1
Structural losses	11.2

As can be seen from **table 6.2**, heat utilised for baking bangles is only 3.1% of the total heat input. The major areas of heat loss are (i) heat in flue gas and (ii) heat loss to bottom ash. Each of the loss areas are discussed in detail in the following sections. The measures to reduce the energy wastage along with expected monetary savings are also provided.

6.3 Recommendations

The muffle furnaces employed in the Firozabad cluster are fabricated locally and very little thought is given to improve the design to enhance the efficiency of the furnaces. Although the heat carried away by the exhaust gases accounts for 46.2% of the total heat input, utilising this heat for combustion air preheating is very difficult. These furnaces employ natural draft and utilising waste heat in the flue gases will require a totally new design, incorporating air preheaters in induced/forced draft configuration. Similarly the loss of 34.6% of input energy due to unburnt carbon in the bottom ash can only be reduced by an improved furnace design, which will lead to proper air-fuel mixing, resulting in efficient combustion of fuel. Keeping the above limitations in mind, the following steps are recommended which can be incorporated in the existing system without drastically increasing the manufacturing cost of the furnace.

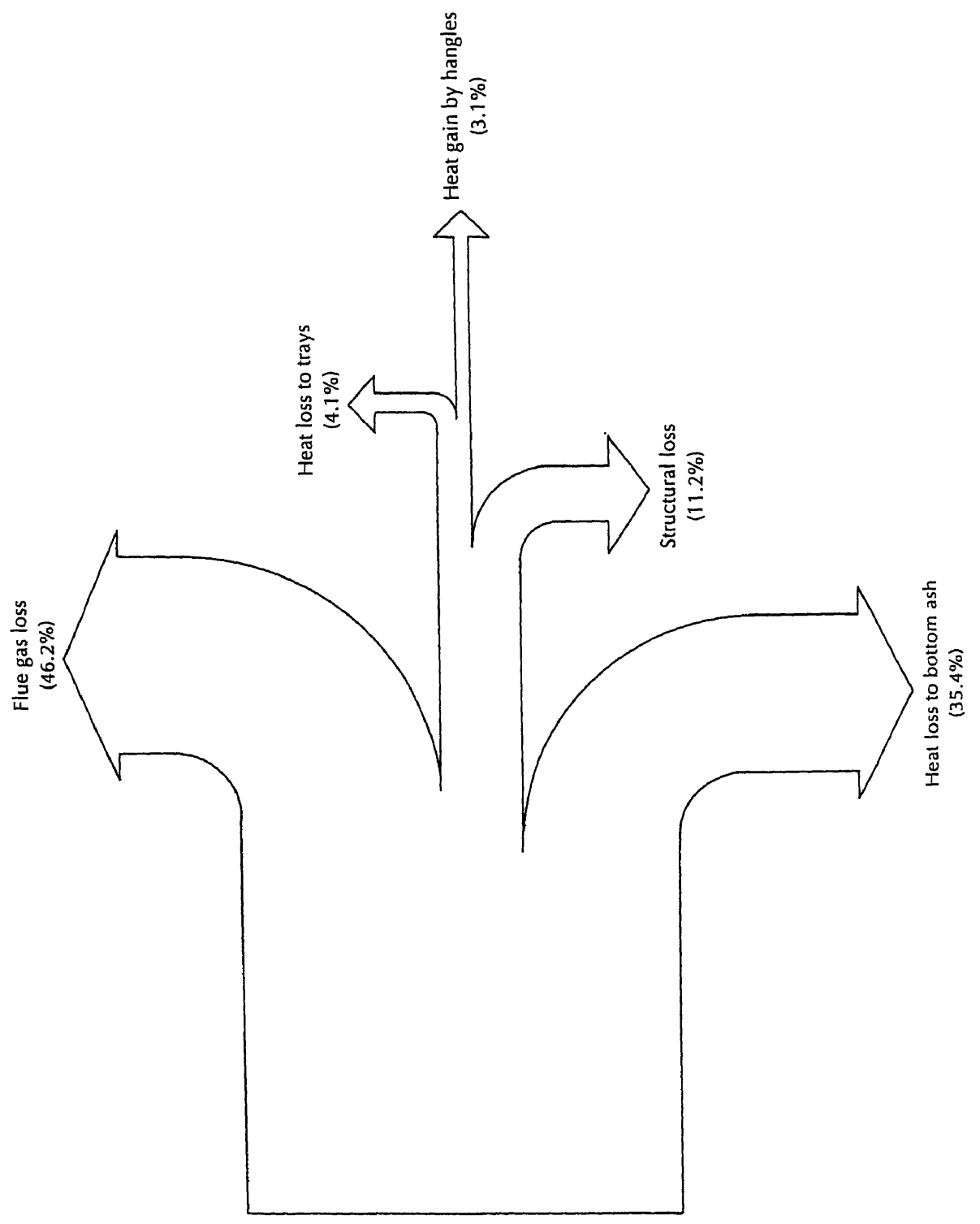


Fig 6.2 Heat balance - Muffle furnace

6.3.1 *Increasing the tier area*

As can be seen from table 6.2, the flue gas loss is 46.2% of the total heat input to the furnace. This is mainly attributable to high flue gas temperature of 710 °C. In order to improve the efficiency of the furnace, it is suggested to increase the tier dimensions to accommodate two trays instead of one. The increased heat transfer area and residence time of the flue gases within the furnaces will ensure that more heat is transformed for the same input energy. The exit flue gas temperature is also expected to drop in the modified furnace design, leading to an overall improvement in the specific coal consumption. The throughput will also double because of the suggested design change.

6.3.2 *Utilising waste heat from pot furnaces*

The maximum temperature attained inside the furnaces is of the order of 480 °C. These units can be conveniently located alongside the units employing pot furnaces. The sensible heat carried away by the hot flue gases from the pot furnaces can be utilised for baking bangles, thus avoiding the use of coal by the pakai bhatties. The exit flue gas temperature from the closed pot furnaces was found to be in excess of 950 °C, which is considered quite adequate for this purpose.

The energy audit study carried out in the closed pot furnace indicates that the heat available in flue gas is of the order of 0.6 Gcal/hr which is equivalent to the energy requirement of five muffle furnaces with the coal consumption of 21 kg/hr. Based on this preliminary assessment, the coal substitution potential of the suggested scheme works out to be 75 tpd if the flue gases from all the 30 operating closed pot furnaces are utilised.

6.4 **Conclusion**

The heat balance of the furnace shows that the useful heat accounts for only 3.1% of the fuel heat input. The major heat loss areas identified in the present system are (i) flue gas heat loss (46.2%) due to high flue gas temperature (ii) unburnt carbon loss (34.6%) due to poor combustion/ash-handling techniques (iii) structural heat loss (11.2%) due to lack of proper insulation. The measures identified for improving the efficiency are (i) increasing tier area and (ii) utilising waste heat in hot flue gases of closed pot furnaces. The reduction of heat losses associated with flue gas and unburnt carbon in bottom ash, however, will require a complete redesigning of the furnace.

Annexure 6.1

Heat balance - muffle furnace

Heat input

Fuel (coal) consumption	=	21 kg/hr
Gross calorific value of coal	=	4500 kcal/kg
Total heat input	=	93,750 kcal/hr

Heat distribution

(1) **Flue gas loss**

(a) Dry flue gas loss

Oxygen content in flue gas	=	8.3%
Excess air level	=	41%
Temperature of flue gas	=	710 °C
Sensible heat in dry flue gas	=	34,672 kcal/hr
Percentage dry flue gas loss	=	37.0%

(b) Heat loss due to hydrogen in fuel

Hydrogen content of fuel	=	0.019 kmol/kg fuel
Total hydrogen content	=	0.39 kmol/hr
Heat taken by hydrogen in fuel	=	6175 kcal/hr
Percentage heat loss due to hydrogen in fuel	=	6.6%

(c) Heat loss due to moisture in fuel

Moisture content of fuel	=	0.003 kmol/kg fuel
Total moisture in fuel	=	0.07 kmol/hr
Heat taken by moisture in fuel	=	1094 kcal/hr
Percentage heat loss due to moisture in fuel	=	1.2%

(d) Heat loss due to moisture in air

Dry bulb temperature	=	42 °C
Wet bulb temperature	=	28 °C
Molal humidity	=	0.033 kmol/kmol dry air
Total moisture in air	=	0.22 kmol/hr
Heat taken by moisture in air	=	1327 kcal/hr
Percentage heat loss due to moisture in air	=	1.4%

Flue gas loss (a+b+c+d)	=	46.2%
-------------------------	---	-------

(2) Heat loss to bottom ash*(a) Heat loss due to unburnt carbon in bottom ash*

Ash content of coal	=	0.35 kg/kg coal
	=	4 kg/hr
Heat content of carbon	=	8051 kcal/kg
Heat loss due to unburnt carbon	=	32,456 kcal/hr
Percentage heat loss due to unburnt carbon in ash	=	34.6%

(b) Heat loss due to sensible heat in bottom ash

Quantity of bottom ash	=	18.8 kg/hr
Temperature of bottom ash	=	200 °C
Specific heat of ash	=	0.25 kcal/kg°C
Sensible heat in bottom ash	=	741 kcal/hr
Percentage heat loss due to sensible heat in ash	=	0.8%

Heat loss to bottom ash (a+b)	=	35.4 %
-------------------------------	---	--------

(3) Heat gain by bangles

Weight of bangles handled	=	32 kg/hr
---------------------------	---	----------

Mean specific heat of glass	=	0.25 kcal/kg°C
Temperature of bangles	=	400 °C
heat gain by bangles	=	2900 kcal/hr
Percentage heat gain by bangles	=	3.1%

(4) Heat loss to trays

Number of trays handled per hour	=	20
Weight of each tray	=	5 kg
Weight of trays handled in one hour	=	100 kg
Mean specific heat of tray material	=	0.114 kcal/kg°C.
Temperature of tray material	=	400 °C
Heat loss to trays	=	4081 kcal/hr
Percentage heat loss to trays	=	4.4%

(5) Structural heat loss

Structural heat loss (by difference)	=	10,510 kcal/hr
Percentage structural heat loss	=	11.2%

Conclusions

The major forms of energy used in the glass industry of Firozabad cluster are coal and R.F.O. The total consumption of coal is estimated at 730 tpd and that of R.F.O. is 25 kL/day for the entire industry cluster. An assessment of energy consumption of different furnace types employed in the cluster indicates that pot furnaces (both open and closed types) account for 48% of the total coal consumption in the industry cluster followed by muffle furnaces which account for 27%. The remaining 25% coal is consumed by tank furnaces. The key results of the energy audit study carried out in the Firozabad cluster are summarised in table 7.1.

Table 7.1. Performance of different furnace types at Firozabad cluster

Furnace type	Specific energy consumption (Gcal/t of melt)	Fuel to melt ratio (kg/kg)	Thermal efficiency (%)
Tank furnace (coal fired)	3.6	0.6	12.7
Tank furnace (oil fired)	2.1	0.2	21.3
Open pot furnace	5.5	1.0	9.8
Closed pot furnace	9.5	1.7	4.7
Muffle furnace	—	—	3.1

Based on the energy audit studies carried out at representative glass melting units at Firozabad, a set of measures were identified which would lead to an improvement in energy efficiency of the units with a corresponding reduction in the pollution load. The recommendations are made under two separate headings:

- (i) Energy conservation measures suggested on the basis of the energy audits, which are unit specific but can be applied to similar units within the cluster. Under this, some newer technology options are also discussed which are successfully used in developed countries but have not found wide applicability in the Indian industry so far; and
- (ii) Long-term measures with a view to upgrade the cluster as a whole.

7.1 Recommendations based on energy audit

7.1.1 Excess air optimisation

There is no provision to check the excess air level in the furnace/annealing lehr in any of the units at Firozabad. The results of the energy audit study indicate that in none of the units the excess air was at an optimum level, leading to lower operating efficiency of the furnaces. For optimising the excess air level, oxygen level in the flue gas need to be monitored. The cost of such an instrument will be Rs 9,000 and the resulting fuel saving by combustion control will most certainly ensure that the investment is paid back within a couple of months. If it is not possible for individual units to have their own flue gas analyser, 3-4 units can pool together and have a common facility for the day to day control of furnace operation.

7.1.2 Waste heat recovery

The energy audit indicates that in all types of furnaces, a substantial portion of the input energy is carried away by the hot exhaust gases. The temperature of exit flue gas ranged from 400 °C for oil fired regenerative tank furnace to 959 °C for closed pot furnace. Even in regenerative tank furnaces, there is a possibility of utilising the sensible heat in the flue gases after the regenerator by incorporating heat recovery system in the passage between the reversal valve and the stack. For furnaces such as closed and open pot type, not employing any heat recovery system, the heat carried away by the flue gases is almost 50% of the total heat input and there is a large scope for utilising this waste heat for air preheating. This, however, will require major modification in the existing furnace design.

7.1.3 Reduction of structural losses

The convective and radiative heat losses from the furnace and the regenerator structures were found to be high in all the furnaces. This is because of the low quality refractory bricks used for the structures. By upgrading the existing insulation by better refractory material/ceramic fibre blankets, it is possible to operate the furnace at higher temperatures, thereby increasing the throughput. There is a possibility of reducing the structural losses by about 50%, which would also result in better working environment for the workers. Upgradation of insulation, however, has to be considered at the time of reconstruction only as modification of the existing structures may lead to thermal imbalance and failure of the structure.

7.1.4 Reduction of unburnt carbon losses in coal fired furnaces

The average unburnt carbon content in the bottom ash of the coal fired furnaces was found to be as high as 21%. The high unburnt carbon thus accounts for one third of the total heat input to the furnace. This loss is attributable to improper air-fuel mixing resulting in inefficient combustion and poor ash handling technique adopted by the plant. The furnace design need to be modified so as to improve the air-fuel mixing considerably to improve the combustion efficiency.

7.1.5 Use of better quality pots

The pots used in the Firozabad cluster has a life of just 20 days. In some cases pot failure occurs within 3-4 days. Each pot failure results in wastage of 0.3 Gcal of energy. The quality of pots can be improved by either upgrading the technology level of the local manufacturers or motivating some established refractory manufacturers to supply good quality pots.

The practice of pot arching¹ is an area where technical support would benefit the glass makers. A small project to develop simple instruments, perhaps pre-programmed to display the correct heating regime, would result in a reduction in the incidence of premature pot failure.

7.1.6 Internal belt return in annealing lehrs

In the annealing lehrs, the heat balance indicates that the heat taken up by the conveyer system is 40-47% of the total heat input to the lehr, the reason being the metallic conveyer belt is heated to 500 °C in heating zone and subsequently cooled down to 45 °C before entering the heating zone again. This loss can be avoided by returning the conveyer within the lehr tunnel. Nearly one-third of the fuel input to the lehr can be reduced with this modified configuration. The possibility of converting the single conveyer system to a split system, i.e. separate conveyers for the heating and cooling zones also needs a detailed investigation. This will reduce the mass of the belt circulating within the radiating zone, which basically acts as a heat sink.

7.1.7 Use of instrumentation

The lack of flue gas analyser for controlling the excess air has already been discussed. In addition, except for one or two units, there is no provision to monitor the temperature of glass melt. There are also no glass level indicators in the furnaces. In glass manufacture, glass level control is an integral part of the process as any change in level will lead to either fall in output or rejection due to excess material in glass. It is therefore essential that the glass level is maintained correctly which would lead to indirect fuel savings.

7.2 Long-term measures

In addition to the measures as outlined above, following long-term measures are also identified which can be explored further.

7.2.1 Improved pot furnace design¹

The existing design of the pot furnaces is inherently inefficient. However very little effort has been spent to improve the basic design. The pot melting design is therefore an area where furnace design changes should be encouraged which would produce large scale fuel savings.

7.2.2 Improved muffle furnaces

Though muffle furnace are individually small consumers of coal, large numbers of the muffle furnaces make them collectively a relatively large scale of fuel user. The present efficiency of the muffle furnace is also very low (3.1%). Reduction of heat losses associated with the flue gases, unburnt carbon loss in bottom ash and structural losses will require a complete redesigning of the furnace¹.

7.2.3 Improved gasifiers for tank furnaces¹

Majority of the coal fired tank furnaces are equipped with separate gasification system. The existing design of the gasification system is outmoded. The conversion efficiency of the system is very poor and a low grade gaseous fuel of variable quality is produced. These gasification plants are prone to stoppages, halting all melting activity. Improvements in the design of these units should be considered as a priority and would result in large scale fuel savings.

7.2.4 Energy pooling

There are about 400 small muffle furnaces (pakai bhatties) in the region, employed for baking of bangles. These units consume good amount of coal and contribute significantly to the pollution load in the area. The maximum temperature requirement inside the furnaces is of the order of 480 °C. It is felt that some of these units can be conveniently located alongside the units employing closed pot furnaces. The heat carried away by the hot flue gases from the pot furnaces can be utilised for the baking of bangles, avoiding the use of coal by the pakai bhatties. The exit flue gas temperature from the pot furnaces was found to be in excess of 950 °C, which is considered quite adequate for this purpose.

7.2.5 Common gasifier concept

In the coal fired tank furnaces, the design of the producer gas plant was found to be outmoded. The conversion efficiency is very poor owing to total absence of control systems, leading to very high coal consumption. Poor coal and ash handling also leads to high unburnt carbon in the bottom ash, which goes as a waste. It is suggested to have a common coal gasification plant which can cater to 4-5 units. The common gasifier can be designed to have a good conversion efficiency and the tank furnaces can be supplied with producer gas generated in a much more energy efficient and cleaner way.

In addition to the measures listed above, some newer technology options are available which are being applied successfully in developed countries with very good results. The applicability of these in relatively smaller units encountered in the Firozabad cluster, however, needs a detailed investigation.

(a) Cullet preheating

Apart from preheating the combustion air, the sensible heat in the flue gases can also be utilised for preheating the cullets before being fed to the furnace. In Firozabad units the share of cullets is quite substantial and ranges between 30-50% of the total batch charge. For a 25 tpd glass melting furnace, energy savings of 0.43 Gcal/hr can be achieved for a cullet ratio of 30% assuming a preheat temperature of 150 °C.

(b) Oxygen enrichment

Oxygen enrichment of combustion air would result in reduction of flue gas loss and higher flame temperature leading to increased melting efficiency. Fuel savings of 8-10% have been reported by the addition of 1.6% oxygen.

(c) Use of bubble system

Use of bubble injector pipes manufactured with high grade stainless steel with recrystallised alumina at the bottom of the furnace results in comparatively cooler glass from the bottom of the tank to the surface resulting in better heat transfer and hence improved thermal efficiency of the furnace.

Annexure 3.1

35

SHRIRAM INSTITUTE FOR INDUSTRIAL RESEARCH

(A UNIT OF SHRIRAM SCIENTIFIC & INDUSTRIAL RESEARCH FOUNDATION, DELHI)
19, UNIVERSITY ROAD, DELHI-110007.

Telegram : 'SRISANDHAN'

Telephone: 7257267

Telex : 031-78051

Fax : 91-11-7257676

E-Mail; Internet: delhi.sriram @ access.net.in

Issued to :

Tata Energy Research Institute (TERI),
India Habitatat Centre (D.S. Block),
Lodhi Road, New Delhi.

TEST CERTIFICATE



No. 46702 406-024-0162

Date: 21.06.94

Your Ref. No.: —

Date: 7.6.94

KIND ATTN.: MR. SOBHANBABU

Sample Particulars:

One sample of coal, was received.

TEST RESULTS

[As received basis]

S.No.	Tests	Test Value
1.	Proximate Analysis, % by mass	
a)	Moisture content,	3.93
b)	Ash content	22.87
c)	Volatile matter	28.55
d)	Fixed carbon (by diff.)	44.65
2.	Gross calorific value, cal/gm	5680

* * * * *

AUTHORISED SIGNATORY

NOTE 1. The result listed refer only to the tested samples as parameters Endorsement of products is neither inferred nor implied
 Liability of our Institute is limited to the invoiced

Annexure 2.1

17

SHRIRAM INSTITUTE FOR INDUSTRIAL RESEARCH

(A UNIT OF SHRIRAM SCIENTIFIC & INDUSTRIAL RESEARCH FOUNDATION, DELHI)
19, UNIVERSITY ROAD, DELHI 0007

Telegram : 'SRISANDHAN'

Telephone : 7257267

Telex : 031-78051

Fax : 91-11-7257676

E-Mail; Internet: delhi.sriram@access.net.in

Issued to :

Tata Energy Research Institute (TERI),
India Habitatat Centre (D.S. Block),
Lodhi Road, New Delhi.

KIND ATTN.: MR. SOBHANBABU

Sample Particulars:

One sample of R.F.D., was received.

TEST CERTIFICATE



No. 146798 486-024-0163

Date: 21.06.94

Your Ref. No.: --

Date: 7.6.94

TEST RESULTS

[As received basis]

S.No. Tests	Test Value
1. Carbon content, % by mass	83.0
2. Hydrogen content, % by mass	11.3
3. Sulphur content, % by mass	3.1
4. Gross calorific cals/gm	10,450

* * * * *

AUTHORISED SIGNATORY

SHRIRAM INSTITUTE FOR INDUSTRIAL RESEARCH

A UNIT OF SHRIRAM SCIENTIFIC & INDUSTRIAL RESEARCH FOUNDATION, DELHI)
UNIVERSITY ROAD, DELHI-110007.

Name: 'SRISANDHAN'

Phone: 7257267

Fax: 031-78051

Tel: 91-11-7257676

TEST CERTIFICATE



Issued to

M/s Tata Energy Research Institute (TERI),
103-Jor Bagh,
New Delhi-3

No. 140612-403-020-0236

Date: 22.3.94

ng

KIND ATTN. :- Mr. J. Mishra

Your Ref. No. ---

Sample Particulars:

Date. ---

One sample described as Lime Stone, was received.

TEST RESULTS

(As received basis)

<u>S.No.</u>	<u>Test Carried Out</u>	<u>Test Value</u>
1.	Calcium Carbonates, (as CaCO_3) % by mass	96.43

AUTHORISED SIGNATORY

1. The results are valid for the tested samples and applicable parameters. Endorsement of products is neither implied nor intended.
2. The validity of our institute is limited to the specified amount.
3. Samples will be destroyed after one month from the date of issue of test certificate unless otherwise specified.
4. This report is not to be reproduced wholly or in part and cannot be used as an evidence in the Court of Law and should not be used in any advertising media without our special permission in writing.

